Notes on the Geology

IN THE

Vicinity of Bennington, Vt.

C. E. Gordon

From the Ninth Report, Vermont State Geologist, 1914.

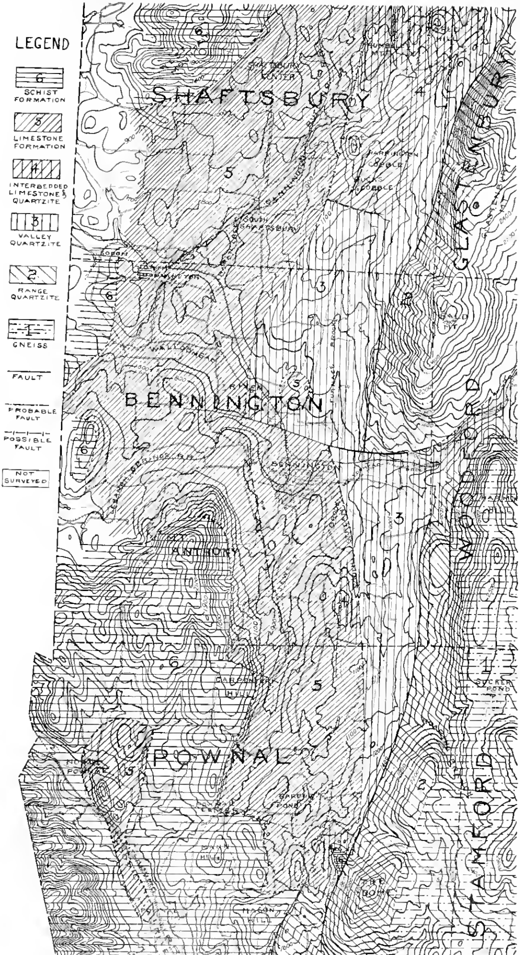
Notes on the Geology

IN THE

Vicinity of Bennington, Vt.

C. E. Gordon

From the Ninth Report, Vermont State Geologist, 1914.



MAP OF BENNINGTON AREA

NOTES ON THE GEOLOGY IN THE VICINITY OF BENNINGTON, VERMONT.

C. E. Gordon.

TABLE OF CONTENTS.

INTRODUCTION.

In the summer of 1912 the writer spent two and one-half weeks in the study of the geology in the vicinity of Bennington, Vt. Though the work speedily involved a detailed inspection from outcrop to outcrop, it was purposely carried out as a reconnaissance. It was expected that another season's work would bring out the broader structural relations among the different formations and lead to more positive conclusions with which to return to the task of mapping the Bennington region.

It has proved inadvisable to carry out the original plan. In view of the brief period spent in the field and the intricate nature of the problem only such notes as were collected and such suggestions as they seem to afford can be offered in this report.

Attention was chiefly given to the hard rock formations. So far as observed, the surface deposits offer no special features of interest.

A map is offered herewith to show the outcrops which were examined. The boundaries of the different formations are drawn in on the basis of these observations. Certain probable structural relations are involved which are also exhibited on the map and discussed in the report.

LOCATION.

The area discussed in this paper is situated in the extreme southwestern part of Vermont and forms approximately the western third of the Bennington quadrangle. The southern boundary of the Bennington sheet is on the west less than one-half a mile, and on the east somewhat more than a mile from the Massachusetts line. The western part of the map includes a strip of the Hoosick quadrangle, varying in width from a mile and a half to two miles, which separates the western margin of the Bennington sheet from the New York State boundary.

The Bennington quadrangle lies between parallels 42° 45′ and 43° north latitude and meridians 73° and 73° 30′ west longitude. The particular parts of the quadrangles discussed in this paper embrace the townships of Pownal and Bennington, the major part of Shaftsbury and small strips on the west of Stamford, Woodford and Glastenbury.

TOPOGRAPHY.

The area includes the southern portion of the great limestone "valley of Vermont." Within the Bennington quadrangle the valley is hemmed in on the east by the steep western slope of the Green Mountain Plateau, which extends as a rugged wilderness through the towns of Stamford, Woodford and Glastenbury. East of Bennington the plateau is cut by the northeast-southwest valley of Walloomsac Brook. North of this stream are the especially rugged masses of Bald and Glastenbury mountains.

The plateau has a high average elevation. "The Dome" in the eastern part of the town of Pownal is 2,750 feet high, while other knobs farther east in Stamford reach an elevation of 3,000 feet or more. Bald Mountain northeast of Bennington is 2,865 feet high; other peaks in Glastenbury Range from this altitude to 3,764 feet in Glastenbury Mountain.

From the western edge of the Green Mountain Plateau the descent to the valley is very steep throughout most of the area. This abrupt topographic break is a striking feature of the landscape.

East of Bennington the western margin of the plateau has been offset to the west a distance of two miles. This east-west break is marked by the course of Walloomsac Brook. Both north

and south of this fault the western margin of the plateau has practically the same general trend to the north-northeast.

By this same offset the valley is shifted to the east at Bennington. South of Bennington the valley extends in a somewhat southerly direction, gradually narrowing up, and ending abruptly at the northern end of Mason Hill in the town of Pownal.

The valley which comes down from the north through the towns of Manchester, Sunderland, Arlington and Shaftsbury is bounded on the west by a high range which terminates west of Shaftsbury Center in West Mountain with an elevation of 2,000 feet. The valley widens out as it enters the quadrangle, its western margin bending west around the southern end of West Mountain. Northwest and west of Bennington is a wide-open valley area which extends west beyond the limits of the map.

The valley south of Bennington is bounded on the west by the Mount Anthony ridge. This ridge begins two miles west of Bennington. Its eastern margin follows a southerly course as far as Pownal Center. Here the ridge bends to the southeast, cutting off the valley of Bennington, and bringing up abruptly in Mason Hill against the Green Mountain Range. Mount Anthony, southwest of Bennington, is 2,345 feet high. The elevation falls off southward to 986 feet at Pownal Center and rises again through 1,500 feet in Mann Hill to 1,660 feet in Mason Hill. The North Adams-Bennington electric railway rises from the 549 feet contour at Pownal village to an altitude of 986 feet at Pownal Center, a vertical distance of 437 feet in about three miles, through the lowest pass in this mass which cuts off the valley of Bennington at the south.

Although there are numerous altitudes in the valley south of Bennington higher than this pass, the essential ridge-like character of the whole stretch from Mount Anthony to Mason Hill is reasonably apparent, its former relatively higher altitude at Pownal Center being obscured by the erosion of the mass between Pownal Center and the bed of the Hoosick. The Mount Anthony portion of the ridge is at the northern end of a southwardly pitching syncline. This fact perhaps in connection with the favor shown by the forces of erosion may account for its present relatively higher altitude.

An inspection of the map will show that in correspondence with the eastward extension of the valley west of Bennington the northern end of the Mount Anthony ridge lies farther east than does the boundary of the valley as formed by West Mountain in Shaftsbury. And the southeastward bend of the Mount Anthony ridge through Mann and Mason hills finds a parallel in the great eastward sweep of the valley region of Williamstown and North Adams around the southern end of Clarksburg Mountain to the Hoosick Range.

DRAINAGE.

In southern Vermont and northern Massachusetts the Green Mountain Range is the divide between the drainage of the Hudson and the Connecticut rivers.

Hoosick River, which rises on the western slope of the Green Mountains in Massachusetts, flows north to North Adams, then westward past Williamstown, and then crosses in a northwesterly direction the extreme southwestern corner of the state of Vermont. Five miles northwest of Hoosick Falls it turns west to join the Hudson.

Near Hoosick Junction, N. Y., the Hoosick receives the waters of Walloomsac River which drains the larger part of the area discussed in this paper. The Walloomsac gathers its headwaters in the Green Mountain Range, five miles east of Bennington, from two large brooks, one of which forks and drains the southern slope of Glastenbury Mountain, while the other forks in a similar manner and drains the northern slopes of Stamford Mountain in its northern extension in the town of Woodford. The sources of these terminal, tributary streams come close to the headwaters of the tributaries of the Deerfield River.

North of Bennington, Furnace Brook and Paran Creek head on a low divide which parts the drainage of the Walloomsac from that of the Batten Kill. They flow south to join the Walloomsac. South of Bennington, South Stream and Jewett Brook flow north from Pownal, the former receiving the drainage of the western slope of Stamford Mountain, and the latter that of the eastern slope of Mount Anthony. South Stream and Jewett Brook join near Bennington and flow into the Walloomsac in the eastern part of the town.

The western slope of the Mount Anthony ridge drains to the Hoosick.

In general, the Walloomsac has an east-west direction across the gneiss, quartzite, limestone and schist. Probably its course was primarily determined by certain important structural features of the region.

GENERAL GEOLOGY.

The core of the Green Mountain Range is made up of gneiss of pre-Cambrian age.

Time did not allow a careful examination of the gneisses within the area. It was extremely difficult to accomplish much on the mountains of the range. The country is still mostly a heavily-wooded wilderness crossed by only two roads and a few overgrown trails. Glastenbury Mountain, which is the most inaccessible, is especially disappointing in outcrops. Seemingly any separation of the elements of its pre-Cambrian core would prove

very difficult under present conditions. Nevertheless, the writer had hoped to make some study of these rocks.

It would seem that an important line of investigation supplementary to the researches of various workers in the pre-Cambrian rocks of the Green Mountain belt is still open.[1] The difficulty in drawing always a sharp line between the Cambrian and the pre-Cambrian was expressed by Professor Pumpelly.[2]

Professor Wolff argued for the presence in the Cambrian ("Vermont Formation") of the Hoosick Range of coarse gneisses, finer-grained banded gneisses, slightly micaceous gneiss, metamorphic gneiss conglomerate and ordinary quartzite conglomerate, these rocks or phases passing into one another along the strike.[3] Later Van Hise[4] made the white gneiss of Hoosick Mountain pre-Cambrian and maintained that there is no transition between the pre-Cambrian igneous and the Cambrian sedimentary.

Keith[5] describes as a result of recent studies in Vermont a great thickness of schist, dolomite, graywacke, quartzite and conglomerate overlain unconformably by the Cambrian quartzite which transgresses the whole of the lower series. This series is classed as Algonkian.

Resting against the gneiss all along the western front of the range within the area is a lofty brow of quartzite which slopes steeply, often precipitously, to the valley on the west. This quartzite is a conspicuous feature for many miles northward in Vermont along the western margin of the Green Mountain Range.

The Woodford-Stamford gneissic core of the Green Mountain Range extends down for a short distance into Massachusetts and terminates in Clarksburg Mountain directly northwest of North Adams. The quartzite formation extends from the town of Pownal southward on the western face of the range and eastward around the southern slope of Clarksburg Mountain. It lies unconformably on the pre-Cambrian (Stamford) gneiss.

In the quartzite formation "east of Bennington," and also on the western slope of Clarksburg Mountain, Dr. C. D. Walcott[6] discovered fossils (Olenellus) which definitely proved the quartzite to be of Lower Cambrian age.

On the east of Clarksburg and Stamford mountains, north from North Adams, the quartzite extends some distance north of the village of Stamford through Hartwellville towards Woodford. Its further northern extension was not followed.

---

[1] C. P. Berkey, Structural and Stratigraphic Features of the Basal Gneisses of the Highlands, Bull. N. Y. State Mus. 107, 1907.
A. Keith, A pre-Cambrian Unconformity in Vermont, Bull. Geol. Soc. Amer., Vol. 25, p. 39.

[2] Mon. U. S. G. S., XXIII, p. 25.

[3] Idem, pp. 35-118.

[4] Bull. U. S. G. S., No. 360, p. 588.

[5] Loc. cit.

[6] The Taconic System of Emmens, Amer. Jour. Sci., Series 3, Vol. XXXV, 1888, pp. 235-236.

In the southern part of the area, as shown on the map of this report, the quartzite on the western slope of the range lies against the schist of Mason Hill, and north of Mason Hill against limestone and schist, and then for the rest of the distance south of Bennington against the quartzite formation of the valley. Southeast of Bennington the floor along the eastern edge of the valley is quartzite. It extends south of the fault along Walloomsac Brook, between the range and the limestone which borders it on the west, and wedges out to the south against the edge of the plateau. The western margin of the range cuts somewhat diagonally northeastward across the general trend of the formations of the valley, south of Bennington.

The valley quartzite south of Bennington is bordered by a broad limestone band which extends south from Bennington and which narrows up and ends somewhat abruptly at the south against Mason Hill. The limestone gives place at the west and south to the schist of the Mount Anthony ridge. At numerous places along the eastern slope of this ridge, north of Pownal Center, the limestone is seen to dip westward beneath the schist. It appears again dipping east along the northwestern slope of Mount Anthony. It forms the high hill just east of the village of North Pownal. It lies on the schist on the west side of the Hoosick, two and a half miles south of North Pownal, and outcrops again on the southwestern slope of Mason Hill along the Williamstown-Pownal road about two miles southeast of Pownal.

East-northeast of Bennington, as described in the topography, the plateau has suffered an offset to the west so that east of Bennington, south of Walloomsac Brook, the quartzite of the valley forms a recess eastward, while north of the stream is the steep southern slope of Bald Mountain and the western quartzite slope of the range lies two miles farther west. Northeast of Bennington from the Walloomsac northward to Buck's Cobble the quartzite was traced as a well-defined band about two miles wide along the east side of the big valley and east and north of Buck's Cobble it was followed somewhat indistinctly as far north as Maple Hill.

The same sharp topographic break which marks the ascent from the valley quartzite to that which fronts the range south of Bennington also distinguishes the relations of Glastenbury Mountain to the valley on the west. North from Buck's Cobble the quartzite is replaced by sharply-folded interbedded limestones and quartzite. West from the margin of the valley quartzite and the westernmost scarps of the hills of interbedded limestones and quartzites, so far as it is possible to learn about this heavily drift-covered region, the valley is underlain by limestone which extends to the eastern foot of West Mountain and around its southern end and south through South Shaftsbury and North Bennington to the northern end of Mount Anthony. West of North Benning-

ton the limestone is mixed somewhat with the schist, but in general bounds the schist formation at the west much as shown on the map.

The quartzite, limestone and schist which have been mentioned form the eastern members of the great Taconic belt of rocks which extends from northern Vermont southward along and near the boundary of New England and New York.

As early as 1872 it had been established through the investigations of the Rev. Augustus Wing that the limestones (Eolian) lying west of the Green Mountain Range contained strata, as shown by fossils, ranging from the Upper Potsdam or Lower Calciferous to the Trenton.[1] From Wing's investigations the term "Calciferous-Chazy-Trenton" was applied to the limestone in general as it outcropped in and west and north of Rutland.

Later studies in the limestones of Dutchess County, New York, by Professors Dana and Dwight showed the presence there of the Georgian, Potsdam, Calciferous and Trenton in rocks having field relations similar to those in northern Vermont and to be regarded as essentially the southwestward continuation of the Stockbridge and Eolian limestone formations of Massachusetts and Vermont.[2]

In 1887, Dr. Walcott carried his studies into the region around Bennington and southward into Massachusetts, and found fossils in the limestone which he assigned to the Chazy-Trenton.[3]

By these and other researches the age of much of the limestone of the Taconic region was shown to be of Ordovician age.

In 1890, Professor Wolff studied the area around Rutland, Vt.[4] He found the limestone (Eolian) of the main Rutland valley to lie conformably along the west side of the valley on the quartzite of Pine Hill. Pine Hill is a ridge just west of Rutland which divides the main limestone valley of Rutland from a smaller limestone valley in Center Rutland. Wolff found the quartzite forming the eastern slope of Pine Hill to bend to the eastward north of Rutland and join the quartzite of the main range. At Pine Hill the quartzite passes upward into limestone through beds of "calcareous quartzite." Cambrian fossils were found in the limestone above the contact with the quartzite. Associated with the quartzite of Pine Hill was a series similar or identical with that associated with the quartzite east of the valley, in each case older than the limestone. The limestone of the Center Rutland valley, just west of Pine Hill, as shown by fossils is of Ordovician age. The general significance of these relations will be appreciated. Part of the Eolian limestone near Rutland was thus indicated to be of probably Lower Cambrian age.

---

[1] Amer. Jour. Sci., Series 3, Vol. IV, 1872; Vol. XIII, 1877.
[2] Papers by W. B. Dwight, Amer. Jour. Sci., 1879-1889.
[3] Amer. Jour. Sci., Series 3, Vol. XXXV, 1888, p. 238.
[4] Bull. Geol. Soc. Amer., 1891, pp. 331-337.

The schists which lie to the west of the limestone of the Vermont valley, extending north from West Mountain in Shaftsbury through East Poultney and beyond, were colored Cambrian by Walcott[1] in a map accompanying his discussion of The Taconic System of Emmons, while the Mount Anthony ridge and the schists to the west of it and around Hoosick Falls, together with certain schist outliers in the limestone of the valley between Shaftsbury and Rutland, were shown as belonging to the Hudson terrane.

In Pownal, at what appears from the description and the map to be on the southwestern side of the Mason Hill mass, Walcott discovered fossils which he described as Trenton, and again on the east side of Mount Anthony, about three miles south of Bennington Center, in the limestone beneath the schist, he found parts of crinoids allied to a form found in the Trenton limestone of New York. Near Hoosick Falls, in limestone about 200 feet below the "shales," he found fossils of the genera Maclurea and Murchisonia and assigned the limestone to the Chazy-Trenton. On the basis of these discoveries, the schist of Mount Anthony and the region about Hoosick Falls was placed in the Hudson terrane and considered to be of Ordovician age.

The terrigenous sediments, described above as colored on Walcott's map as Georgian, were so designated on the basis of fossils of Lower (then called Middle) Cambrian age, contained in thin interbedded limestones. These fossils were "distributed at various horizons throughout the 14,000 feet or more of strata referred to this terrane." These slaty, or phyllitic rocks Walcott regarded as the off-shore equivalent of the quartzite of the Green Mountain Range. Two belts of the Cambrian slates are shown with a belt of the Hudson terrane faulted in between them.

Probably most of the eastern portion of Walcott's eastern Georgian belt, including West Mountain, is of Ordovician age.

GENERAL RELATIONS OF GEOLOGY AND TOPOGRAPHY.

The whole region is mountainous in structure. Viewing it as a whole, we find that the mountain folds have been truncated, exposing the older rocks along the anticlinal axes, while in the synclinoria the younger strata were folded down and thereby preserved. In the valleys certain strata, which primarily belonged to faulted upthrust blocks, have been dropped back by normal adjustment faulting and are now exposed by erosion in abnormal relation to adjacent strata.

Professor Davis[2] early described the region as a worn-down mountain area peneplaned by sub-aerial agencies. The higher

[1] Amer. Jour. Sci., Series 3, Vol. XXXV, 1888.
[2] Mon. Nat. Geogr. Soc., Vol. 1, 1895, pp. 279-284.

eminences were interpreted as monadnocks. Professor Dale[1] later questioned the peneplaned character of the Taconic physiography on the ground that the peneplain theory would require for the region, as shown by its history, an elevation of from 1,500 to 2,000 feet at the beginning of the Tertiary and that subsequent time was seemingly not long enough to carve to its present condition a dissected peneplain, if, as seemed likely, such sculpture involved the removal of at least half of the Taconic topographic belt since its post-Ordovician elevation.

Recently Professor Barrell[2] has come forward with the view that much of the Piedmont belt of southern New England and New Jersey, which is generally regarded as part of a great peneplaned region, could be explained as the result of marine planation at right angles to the lines of drainage. In western Massachusetts and Connecticut and extending into New York and southward, he has described a more or less clearly recognizable series of wave-cut terraces at different levels, showing the former presence of the sea, at the time of its maximum transgression, a long distance inland from the margin of the present coastal plain. He correlates the terraces with definite formations of the present coastal plain and recognizes in the planes of disconformity among the deposits of the present plain the record of the uplifts that successively elevated the different terraces, assuming, of course, that the oscillitary movement reached the coastal plain.

Condensed Table of Hard Rock Formations.

Age.	Formation.	Members.
Cambro-Ordovician.	Schist.	Shales. Slates. Grits, Phyllites. Calcareous Schists. Sericite Schist.
	Limestone.	Marbles. Compact and granular crystalline limestones. Limestones and calcareous quartzites with interbedded quartzite. Quartzite. Quartzitic schist.
Basal Cambrian.	"Vermont Formation."	Schistose quartzite. Dense compact quartzite. "Granular quartz rock." Conglomerate.
	Unconformity.	
Pre-Cambrian.		Gneiss of Stamford Mountain and Harmon Hill.

[1] Bull. U. S. G. Sur. No. 272, p. 33.
[2] Bull. Geol. Soc. Amer., Vol. 24, pp. 688-690.

At the time of its farthest advance the sea is believed to have reached the south side of the Adirondacks and the southeastern side of the Green Mountains in Massachusetts, there cutting the oldest, or "Becket terrace" in middle Cretaceous time. Later terraces range from this epoch into the Pleistocene.

The absence of unconsolidated marine deposits far inland from the margin of the present coastal plain is held not to invalidate the claims of this later view of the Piedmont region, since such deposits might well have been almost completely if not quite removed by erosion.

The approximate elevation of the inner margin of the oldest, or Becket terrace, is now 2,400 feet, but the region is known to have undergone progressive warping.

THE GNEISS AND ASSOCIATED QUARTZITE.

GENERAL DESCRIPTION.

The gneiss was examined on the western slope of "The Dome" and on the western and northern slopes and summit of Harmon Hill. The western boundary of the gneiss, where shown, is drawn in somewhat arbitrarily. The boundary was not touched on Bald or Glastenbury mountains.

On the southwestern side of "The Dome" the quartzite rests unconformably on the gneiss. West-southwest of this eminence, lower down the slope and about on the 1,700-foot contour, in a valley recess southeast of the pond, the gneiss is exposed in a wet-weather gulley. The rock is in place, but the strike and dip of the foliation could not be satisfactorily determined. Northward from this outcrop along the steep slope east of the pond, gneiss talus boulders were common with some admixture of quartzite northward.

At a point due east from the pond, well up the very steep slope at this point, limestone and interbedded calcareous quartzite, quite like that which will presently be described as commonly occurring apparently at no great distance above the quartzite of the valley south and north of Bennington, forms the slope with strike N. 17° E. and dip 25° easterly. This limestone at a short distance to the northeastward passes upward into black, shiny, graphitic-looking schist, or phyllite, which forms the summit of the sharp spur that sticks out northeastward from the range in the direction of Barber's Pond. Descending this spur towards its apex, the phyllite, which seems to be conformable, gives place to limestone and interbedded quartzitic layers like those described above. The phyllite is less gritty than the schist of Mason and Mann hills, and differs somewhat from any which I have elsewhere observed in the area. I have not elsewhere found it associated with these particular limestone beds as shown in this spur. The relations are peculiar and difficult of explanation. The phyl-

lite apparently lies in a syncline of limestone closed northwestward and pitching towards the range. Northwest of the log cabin the limestone beds stand at high angle.

I have drawn a fault, from the outcrop of gneiss mentioned above, north-northeastward where this spur abuts against the range to show the prevailing tendency of the older rocks to appear against the younger by reverse faulting. To what extent the older rocks moved upward will be discussed later on. This spur is mentioned in connection with the gneiss as it helps to develop the writer's interpretation of the structural relations along the western margin of the range.

Northeast of this spur is another sharp recess, on the eastern edge of which ascends the road that crosses the range to Stamford. Along this road just before it makes the abrupt turn up the steeper slope of the mountain limestone outcrops in the road. Definite readings could not be made. The limestone is not succeeded by any outcrop along the road for a long distance. Near the summit thin-bedded quartzite with irregular, rusty parting surfaces outcrops in the road and woods with low westerly dip.

North of the mountain road to Stamford the western slope of the range is quartzite above the lower drift-covered portion. It was observed at places, in the woods, dipping gently westward and in some places lying nearly flat. Near the summit the thin-bedded quartzite was observed passing upward into gritty schist which, in some places showed great similarity to certain lower members of the schist formation overlying the limestone in Mount Anthony.

The valley occupied by the pond northwest of the gneiss outcrop, which was described above, is apparently underlain by limestone, but south of this recess the quartzite of the range extends a half mile or more west of the outcrops of gneiss and along Reservoir Brook abuts against the schist of Mason Hill. The quartzite stands as a fairly high scarp above the brook about one mile north of the Williamstown reservoir. At this place it is a thick-bedded, compact white rock. Higher up the brook it becomes more thinly-bedded and the scarp in consequence diminishes in abruptness to the northward. Where the scarp is composed of the compact heavy quartzite, we have exposed lower beds of that formation. The dip is flat, or slightly easterly. The general relations are shown in figure 27.

Along the mountain road east of Reservoir Brook and between the brook and road are frequent low-lying ledges of the thin-bedded quartzite, having a notably flattish position. The quartzite is often rather a quartzite-schist with well-developed micaceous bands. Ledges are often "flaggy" and under the hammer break into irregular chips with rusty parting planes. Along the brook east of the mountain road, at the base of the

steeper slope on the west of the southward extension of "The Dome," it changes to a fine-grained quartz-pebble conglomerate. Along the mountain road just before it leaves the woods at the north, just east of the source of Reservoir Brook, the thin-bedded quartzite is badly crumbled and frequently carries veinlets of quartz. East of these outcrops is the thin-bedded, flaggy quartzite which prevails over most of this flat hill lying southwest of "The Dome."

Along the higher portion of the western slope of the range the quartzite, as far as the physical difficulties made it possible, was traced from Roaring Branch to the southern end of Harmon Hill. On the western slope of this hill the gneiss comes down close to the base and stands in ledges from 30 to 40 feet above the quartzite. The contact is clearly a faulted one. Here the upthrust brought the gneiss against the quartzite, as now exposed. The quartzite dips slightly to the westward and passes by gradual slope into the valley west of the hill.

The actual contact of gneiss and quartzite was not observed, but ledges of the two formations are less than 100 feet apart. The quartzite strikes nearly north, or slightly west of north, while the strike of the foliation of gneiss is east of north. The relations here described are best observed in the pasture about one-half mile northeast of Woodward's Corner.

The fault between the gneiss and quartzite I have represented as dying away southward in the quartzite, its place being taken by another break farther west which faulted the quartzite of the range against that of the valley.

From its outcrops near the quartzite along the fault, the gneiss continues up the slope to the summit of the hill. A reading at the summit gave the strike of the foliation as N. 60° E. and the dip 80° NW.

The relatively ancient character of the foliation of the gneiss is impressive. It seemingly antedates the deposition of the quartzite, as shown by the discordance in strike and dip, and belongs to a pre-Cambrian mountain-building time. The gneiss had acquired practically its present foliated condition before the deposition of the quartzite.

East of Bennington, in the valley along the Woodford road which skirts the northern end of Harmon Hill, the quartzite outcrops in frequent ledges. Less than a mile east of the trestle bridge across the Walloomsac the road has been blasted through a heavy ledge of quartzite which rises abruptly from the bed of the brook. This ledge is nearly along the northward projection of the quartzite just west of the fault at Harmon Hill. It also probably lies south of the cross fault, which is represented on the map as cutting off the Bald Mountain mass at the south.

Numerous ledges of the quartzite outcrop along the road to the eastward. This formation was traced from the fork in the

road, along Walloomsac Brook to the junction of Bickford Hollow and Bolles brooks, and also beyond the forks along City Stream for three-fourths of a mile. Along the upper reaches of the Walloomsac the quartzite is the rusty, flaggy rock which has been described.

A mile from the fork, along the Woodford road, the gneiss of Harmon Hill outcrops in the road, showing the foliation strike as N. 50° E. and the dip 70° E. The quartzite was not traced farther east.

It seems likely that a great irregular fault cuts off the gneiss of Harmon Hill at the northern end, and that this formation rests with faulted contact against the quartzite in the valley north of the hill.

PETROGRAPHY OF THE HARMON HILL GNEISS.

The gneiss as it appears along the Woodford road is a rather fine-grained biotite gneiss without pronounced foliation. The biotite appears in fine flakes uniformly distributed in the rock both across and with the foliation. The thin section shows a granitoid texture with prominent anhydrons of feldspar and quartz of allotriomorphic type with biotite of igneous habit and distribution, usually enclosed in the feldspars. The feldspars are somewhat decomposed and are partly clouded with kaolinite and other decomposition products.

The gneiss at times carries coarser bands of quartz and feldspar which roughly alternate with micaceous bands of a texture similar to the finer-grained gneiss described above. Where freshest the feldspars appear to be chiefly plagioclase. Zircon occurs as an accessory. There appear to be no pronounced strain effects. While there is usually a decided wavy extinction of the quartz, the twinning lamellae of the feldspars are not broken perceptibly and show uniform width along their entire lengths.

The rock at the top of the hill is essentially the same as that along the Woodford road, although it is more prominently gneissic. It has the same general texture in thin section and the same mineralogy, with the addition of some microcline.

The rock near the contact with the quartzite along the western slope of the hill clearly shows the effect of shearing. In the hand specimen it appears crushed and when hit by the hammer breaks along smoothed surfaces. In thin section the quartz appear shattered. The fragments have recrystallized and healed without extensive migration. Where before were large quartz crystals are now patchworks of small grains with independent extinction. The plagioclase shows badly bent and pinched out lamellae and the biotites are broken into numerous fragments and dustings.

INTERPRETATION.

So far as I have observed, there is little evidence of folding in the gneiss and not much of shearing, except in the zone of faulting.

From the gentle dip of the quartzite and its frequent almost flat position we may suppose that this formation, as a general rule was not violently folded. At places accommodation was effected in the gneiss by shearing, but over large areas, so far as observed, even shearing is inconspicuous. The quartzite was folded somewhat in the general movement of elevation and in some places buckled into small folds, as, for example, along lines on which the gneiss was shoved up on the quartzite, the break often dying away along the line into a fold in the quartzite.

The breaks were primarily initiated by the crystalline gneissic substratum refusing to fold. The tendency to rupture was doubtless augmented by the covering of heavy quartzite which was also reluctant to fold.

The release of the highly crystalline substratum was apparently effected by numerous breaks along the strike. At some places, for some reason, the rupture occurred earlier than at others and at some places farther west, so to speak, than at others, the effect being a sort of echelon of faults along the western margin of the range.

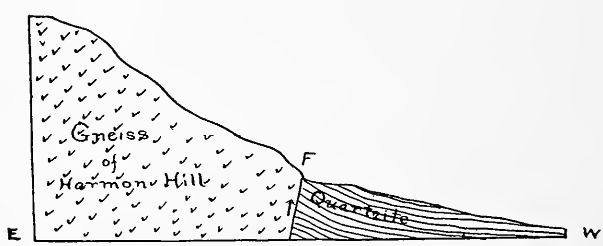


FIGURE 26.—Generalized section to show reversed fault between the gneiss and quartzite on the west of Harmon Hill.

The fault on the west of Harmon Hill, figure 26, is represented as dying away southward in the quartzite. Its place is taken by another break farther west by which the quartzite rests against younger quartzite at the west. The latter fault is represented as dying away northward in the quartzite west of Harmon Hill. Southward it is drawn near the base of the slope as far south as the latitude of Barber's Pond. It then probably merges with a break that bounds the valley quartzite south of Bennington on the west or passes directly into the fault shown along the western slope of "The Dome."

The fault on the west of "The Dome" dies away southward, its place being taken by another break farther west by which the quartzite was thrown against the schist of Mason Hill along

Reservoir Brook. My interpretation of the probable relations at Mason Hill are shown in figure 27. The famous "Sand Springs,"

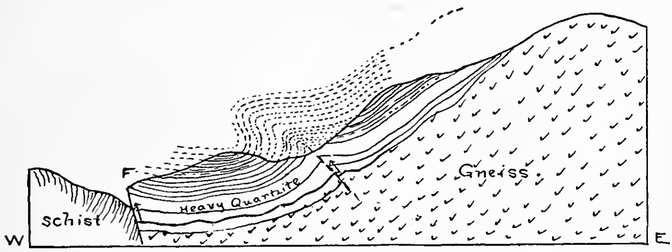


FIGURE 27.—Generalized section to show the interpretation of the relations at Mason Hill.

a resort two miles northwest of Williamstown, lies along or close to the southward extension of the Mason Hill fault along Reservoir Brook. This spring issues from clear white sand and in winter and summer, as well as in dry and wet seasons, gives an average flow of 400 gallons a minute. The temperature of the water in winter and summer is about 76° Fah. Its freedom from organic contamination and its remarkable mineral content have given the water a wide reputation for medicinal purposes, both for drinking and bathing. The water is now extensively used for the manufacture of "soft drinks," and the excess flow is utilized for a swimming pool. The following analysis was made by Leverett H. Mears, Professor of Chemistry at Williams College.

	Parts per 100,000.
Lithium chloride	0.0353
Sodium chloride	.0768
Acid calcium carbonate	3.2249
Acid magnesium carbonate	2.6479
Calcium sulphate	.7262
Aluminium sesquioxide	.0325
Iron sesquioxide	.0075
Silica	.7026
Sodium carbonate	.4641
	7.9178

The spring issues from the drift, but its constancy, temperature and mineral content suggest a deep-seated source and argue for the great depth of the fault along which it comes.

The fault shown on the map as bordering the quartzite of the range on the west of the low hill just southwest of Harmon Hill is marked by a rugged talus slope across the edge of the quartzite beds just within the edge of the woods southwest of Woodward Corner and Harmon Hill. This scarp and talus was distinctly followed southward for two miles.

There would have been a tendency to break across the strike on the north of this hill, but it seems more likely that the fault

on the west dies away northward owing to compensation by the fault at the east on the west of Harmon Hill.

Southwest of "The Dome," however, there may be a cross fracture for here the quartzite passes northward into limestone. This limestone may, however, be of Cambrian age as discussed beyond.

The "valley quartzite" is represented as probably wedging out to the southward against the range. The quartzite of the range cuts somewhat diagonally across the general trend of the formations in the valley.

The presence of the quartzite formation high up on the slopes of the range and its eastward extension along Walloomsac Brook in themselves strongly argue for the former extension of this formation over the range toward Woodford. The quartzite, as noted in the discussion of the general geology, extends northward from the southern end of Clarksburg Mountain for a long distance toward Woodford on the east of Stamford Mountain. The presence of the quartzite formation along the headwaters of the Walloomsac and in City Stream may be explained by down-faulting.

THE VALLEY QUARTZITE SOUTH OF BENNINGTON.

By this term may be understood the quartzite formation as it outcrops in the valley west of the prominent gneiss or quartzite scarps and slopes of the range.

East of Bennington outcrops are concealed by modified drift as far east as the foot of Harmon Hill and the outcrop along the Woodford road a mile east of the bridge across the Walloomsac.

South of Walloomsac Brook the only outcrop observed between the range and South Stream was two and a half miles south of the brook, so effectually are outcrops concealed by the heavy surface deposits over this area. Near the south road to Sucker Pond, about half way between the foot of the range and the old lumber mill along South Stream, where this road makes its sharp bend southward, are outcrops of quartzite.

Drift conceals this formation between these outcrops and South Stream. In the bed of the latter, near the bridge, a fourth of a mile north of the old lumber mill, the quartzite gives a strike of N. 42° E. and a dip of 17° SE. From the bed of the stream the topography eastward rises by gentle slope to the foot of the range. Near the old lumber mill the limestone is interbedded with calcareous quartzite at the dam and in and west of the road just above the stream. Similar beds outcrop along the stream at the gentle rapids five or six hundred yards south of the dam. All the beds along the stream have a notably flattish position.

The valley quartzite and its associated interbedded series were not traced farther south, but probably continue under the drift for a distance of three or more miles southward to the foot

of the range, seemingly wedging out where the limestone extends down into the recess southeast of Barber's Pond.

Northward along the road that follows South Stream to Bennington, about three-fourths of a mile north of the old lumber mill, the interbedded calcareous quartzite and limestone outcrop in the bed of the stream and on each bank. The beds vary from two to four to six inches in thickness and dip gently eastward; a stratum of limestone beds alternating with a stratum of calcareous quartzite. The road to Bennington forks just north of these outcrops. At the fork a ledge of quartzite was blasted to make way for the road. The quartzite in this ledge is sheared vertically, apparently at right angles to the bedding, which, however, is obliterated, and along the shearing planes are numerous crystals of pyrite which have stained the sheared surfaces a rusty brown. The five feet of vertical exposure here is all dense steel-blue quartzite. Two or three outcrops of the quartzite were noted farther north along the east road from this fork.

The data are meager for forming definite conclusions, but from the sheared quartzite just described and the general flat position of the beds, I imagine the valley quartzite to have buckled very little, but on the contrary, to have faulted against the rocks farther west. In the course of adjustments following reverse faulting it would probably have dropped back again by normal faulting along earlier thrust planes so that its present position would be misleading as to its real history. The valley quartzite east of Bennington would have folded with that of the range until the great breaks along its eastern and northern margin occurred when it would have slumped somewhat. The amount of displacement of the valley quartzite along its western margin would have been less than that which occurred in the quartzite and gneiss of the range on the principle that the reverse faulting would tend to die away westward.

THE VALLEY QUARTZITE AND INTERBEDDED LIMESTONES AND QUARTZITE NORTH OF BENNINGTON.

Northwest of Bennington on the south bank of the Walloomsac, at the edge of the golf links of the Mount Anthony Golf Club, near the covered bridge, quartzite is interstratified with limestone, the whole forming a gentle arch. At this place there is no shearing and the outcrop is considered to lie east of the probable western boundary of the valley quartzite in its occurrence north of Bennington.

A mile and a half north of the outcrops at the golf links along the road to South Shaftsbury, the quartzite outcrops in the road. North of this outcrop two roads leave the South Shaftsbury road, one going west, the other east. On the latter, close to

the main road and south and north of it, ascending the slope to the eastward, are numerous ledges of the quartzite lying nearly flat, or dipping gently eastward. This road is locally known as the "Stony Hill road."

An almost continuous outcrop of the quartzite was traced northward through the woods along the edge of the hill, one-fourth of a mile east of the South Shaftsbury road, for nearly a mile. Westward the quartzite descends by gentle slope to the South Shaftsbury road, but the slope is across the edges of the quartzite beds. Eastward the formation passes under drift.

North of the next crossroad, the quartzite forms a high hill just northwest of Wait's Corner. Well up the rather steep eastern slope of this hill are great patches of white granular quartzite dipping easterly. The southern end of this hill is a berry pasture. North of the pasture are thick woods with some clearings. Through this wood the quartzite was followed nearly to the next crossroad running from South Shaftsbury to the Madison school. The northernmost outcrop of the quartzite, as thus followed from Bennington northward was noted near Buck's Corner. North of the South Shaftsbury crossroad begins the southern limestone slope of Buck's Cobble. The limestone continues northward through Harrington Cobble and across the next road and then passes under a gentle west slope, lying between Harrington Cobble and the crossroad which skirts Trumbull Mountain on the south.

East of the north-south road on the east of Buck's Cobble, everything is concealed by drift as far north as Maple Hill. The quartzite forms the eastern slope of Maple Hill and outcrops a mile eastward at the apex of the loop formed by the road that runs to the base of the range, east of Maple Hill. At the latter place, within a space of 50 feet, the structure exhibited in figure 28 was shown. The quartzite is thin-bedded and lies

FIGURE 28.—Structure in limestone and quartzite east of Maple Hill.

quite flat. At the west it bends downward and passes beneath limestone which is folded down at a rather sharp angle.

North of Maple Hill, south of the loop road, in the thick woods on the north side of a deep gully, the quartzite in vertical section shows the structure exhibited in figure 29. The folding of the quartzite here, as contrasted with its flat position farther south, is in line with the relations exhibited in the "Cobbles" west of Maple Hill, which will be described presently.

Along the road leading to the old abandoned hamlet of Fayville (see Equinox sheet; not shown on the map of this report)

PLATE LXIX.

A. BUCK'S COBBLE, A VIEW LOOKING NORTH.

B. FOLD IN INTERBEDDED QUARTZITE ON TRUMBULL MT. ON THE CREST OF AN OVERTURNED ANTICLINE.

quartzite outcrops in the bed of the brook. It is a heavy, compact rock in beds from 2 to 5 feet thick and strikes N. 25° W. with a dip about 12° S. W.

It will thus be seen that a band of quartzite 2 miles wide extends north from Bennington as far as the crossroad from South Shaftsbury to the Madison School. So far as observed, there is no limestone overlying or interbedded with the quartzite, within this distance, except at the south near Bennington. Along the road leading northeast from the covered bridge at the Mount Anthony Golf Club links, a half mile north of the railroad, limestone outcrops in the road and in the fields east of it are numerous ledges. A reading gave the strike as N. 13° W. and a dip 9° westerly. Because of their apparent superjacent conformity to the quartzite and because of the resemblance to other limestone, which the writer has elsewhere observed in the Taconic belt, lying a little way above the quartzite, the rock was closely searched for Lower Cambrian fossils, but without success. How extensive this limestone is north and east of these outcrops it was not possible to tell on account of the drift. Southward from them there are no outcrops in Bennington north of Main St., so far as observed. These ledges probably represent an outlier resting on the quartzite and conformable with it.

The sudden transition from quartzite, east of Buck's Corner on the South Shaftsbury crossroad to the limestone of Buck's Cobble on the north of it suggests a cross fault between them. The high scarp on the west of the Cobble suggests a strike fault here, which extends north on the left of Harrington Cobble, beyond which it apparently shortly dies out. Harrington Cobble has much the same structural outlines as Buck's Cobble (see Plate LXIX, A) but its western slope is less precipitous and merges gradually into the eastern slope of Hale Mountain at the west. The western slope of Hale Mountain is, however, decidedly steep and scarp-like. The limestone on the east slope of Buck's and Harrington Cobbles dips eastward at a rather high angle. On Hale Mountain a reading on the eastern slope at the southern end gave strike N. 19° E., dip 40° E., and on the northern slope, strike N. 46° E., dip 23° E.

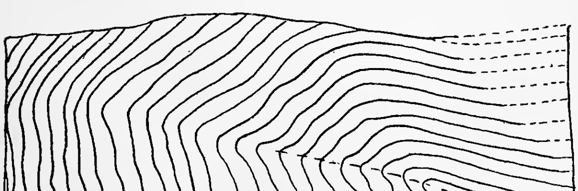


FIGURE 29.—Quartzite north of Maple Hill.

As contrasted with the hills at the north, now to be described, the limestones of Buck's and Harrington Cobbles and of

Hale Mountain, so far as observed, show no associated quartzite.

At Maple Hill, the limestone which forms the summit and western slopes exhibits in cross section a close folding and slight overturning which are features in line with the folding of the quartzite (as shown in figure 29) at the northeastern end of the hill. Near the base of the western slope the rock is a slightly banded, rusty, medium-grained "buckwheat" marble. It dips eastward at a high angle.

The hill just west across the road from Maple Hill is limestone. On the eastern slope the beds dip eastward. In this hill there is no associated quartzite. Its western slope is steep and suggests a break as also does the slope on the west of Maple Hill. (See Plate LXIX, B).

The next hill to the west shows quartzite on the eastern slope dipping eastward, but at the summit the dip is westward, indicating overturning. My notes indicate that it is interbedded with limestone and calcareous quartzite.

The next hill on the west is Trumbull Mountain. At the south end of this hill, which rises very steeply from the road which skirts it on the south, the quartzite forms the eastern slope, dipping east. Near the top of the hill, but 300 or 400 yards east from the summit of the western slope, quartzite shows a structure seen in Plate LXX, A, which is a view looking north. It will be observed that the bed of quartzite dips east on the right of the photograph and west on the left. Associated limestone beds outcrop near by at the south on the southern pitch of the hill, also dipping slightly west. A little farther west they stand nearly vertical and on the western slope dip to the east, forming an overturned anticline.

Similar relations were shown in the hill east of Shaftsbury one mile north. (See Equinox sheet). Quartzite which forms the eastern slope of this hill outcrops at the western base of the next hill to the east with strike N. 25° E. and dip of 24° easterly.

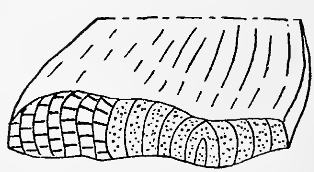


FIGURE 30.—Structure seen in hill near Shaftsbury, interbedded limestone and quartzite.

A wide swampy track borders the steep western scarp of Trumbull Mountain. West of the northward extension of this swamp, east-southeast of Shaftsbury (see Equinox sheet), is another high hill, showing interbedded limestone and quartzite, standing at high angles on the summit. At one place the structure was similar to the accompanying figure 30. On the top of

A. LOOKING NORTH FROM HARRINGTON COBBLE. TRUMBULL MOUNTAIN ON THE LEFT. MAPLE HILL ON THE RIGHT.

B. MINOR COMPRESSED FOLDS IN LIMESTONE OVERTURNED TO THE WEST, ONE-HALF MILE NORTH OF HARRINGTON COBBLE.

the hill the limestone was folded down in a minor synclinal. The structure was interpreted as that of an anticline, but with one or more infoldings along its crest.

South of the transverse series of hills beginning with Maple Hill on the east and ending with Trumbull Mountain, between them and Harrington Cobble and Hale Mountain at the south, is a gentle westward slope of low relief. Plate LXX, A, is a view looking north from the summit of Harrington Cobble across this slope. The scarp-like character of the western slopes of the hills in the distance is brought out in the photograph. The 100-foot contours of the map of this report do not bring out these hills as sharply as do the 20-foot contours of the United States topographic sheet. In the foreground of the plate is the gentle, northern drift-covered slope of Harrington Cobble. The northern slope of Hale Mountain is more abrupt. In the southern portion of the gentle western slope, north of the crossroad on the north of Harrington Cobble, are numerous ledges of limestone. In the brook that crosses this portion of the slope the limestone dips gently westward. Plate LXX, B, gives a view of a portion of a limestone ledge 500 or 600 yards south of the brook. This ledge was interpreted as connecting under the drift with Harrington Cobble and as genetically a part of it, thus revealing the close overturned folding that caused the Cobble.

The general flat position of the quartzite in the broad band north of Bennington indicates that it was not folded much. It buckled a little. In its southern portion a downward fold caught and preserved the limestone outlier north of Bennington. At the northern end an upward bulge formed the long high hill of quartzite south of Buck's Cobble.

All the different hills that have been described in the eastern part of Shaftsbury are of similar genetic type, including the hill of quartzite south of Buck's Cobble. They form long camel-hump arches along the strike with anticlinal structure and all are overturned. Probably all have suffered some overthrusting or developed a strong tendency in that direction. It may be that Buck's and Harrington Cobbles and Hale Mountain had a quartzite member of the interbedded series at one time covering them, but not being so violently folded as the hills farther north, there was no infolding of the quartzite along their crests. It is also possible that the limestone of these Cobbles belongs to a higher horizon than the interbedded limestones and quartzites farther north and that the latter did not reach the surface in Buck's and Harrington Cobbles. The former view, however, seems more likely because the limestone outlier north of Bennington would seem to suggest that the quartzite was succeeded by a certain thickness of limestone before the deposition of the interbedded series and the occurrence of the quartzite at the surface at the south points to diminishing reversed faulting northward so that

Buck's and Harrington Cobbles with Hale Mountain take an intermediate position with respect to the quartzite south of them and the interbedded series at the north. The exact relation of the broad quartzite band to the adjacent limestone on the west could not be positively determined, but I believe it is a faulted one. An intersecting cross fault south of Buck's Cobble dies away eastward. North of this break folding was more violent, the tendency towards which is recorded in the quartzite at the high hill just south of Buck's Cobble. The tendency to folding increased northward and inversely as the tendency to upthrust of the lower beds diminished.

If there is a reversed fault on the west of the broad band of quartzite it becomes a question how far north it should be drawn. The interbedded series appear to be at no great distance above the basal quartzite, whether we reason from the surface succession northward from Bennington or eastward from the range through Maple Hill, and I have drawn a probable break northward to the limit of the map to show the probable close age relation of all the rocks of this broad band on the east of the valley north of Bennington with intervening probable strike faults between this major break and the foot of the range.

In view of the heavy drift covering in the central and western part of Shaftsbury the probable stratigraphical relations of the east and west portions of the valley in this town are hard to work out. If there is a reversed fault all along the western edge of the quartzite and the series of "Cobbles" north of it, it would mean that the interbedded series underwent some folding before the break occurred and were caught at whatever stage of folding they had attained when the heavy quartzite basal member broke.

South of Bennington the interbedded series lies flat for the most part. The high hill just west of the brook that joins South Stream three-fourths of a mile northwest of the old lumber mill shows interbedded calcareous quartzite and limestone like those in the hills of Shaftsbury and obeys a similar arching tendency along the strike. A reading on the steep eastern slope of this hill gave the strike as N. 35° E. and the dip 80° E. At the northern end of the hill a reading gave strike N. 33° E. and dip 70° W.

Placing this hill with the valley quartzite formation the western boundary of the latter should perhaps be drawn through or on the west of this hill and southward so as to include the spur sticking out northwest from the range towards Barber's Pond. The limestone of the base of this spur in its lithology recalls the limestone of the outlier north of Bennington and underlies the interbedded upper series of the spur.

Possibly the western margin should be drawn even farther west to include certain outcrops south of Meyer's house on the

extreme northeastern slope of Mason Hill which are lithologically similar to the limestones just mentioned.

The calcareous quartzites of the interbedded series so strongly resemble the quartzite that one must always carefully examine them to be sure. They weather to look like the quartzite although frequently showing a pitted surface. These siliceous limestones, as they may be equally well designated, effervesce rather strongly with cold dilute acid and under the microscope show an approximately equivalent amount of calcite and quartz distributed in grains over the section in such manner as to indicate detrital origin for both and free admixture during deposition. The siliceous elements of the thin section show some microcline and other feldspar but are predominately quartz.

THE LIMESTONE FORMATION IN AND SOUTH OF BENNINGTON.

On Hillside street in Bennington, near the house of J. T. Remington, the limestone as blasted in the road shows the structure as exhibited in figure 31. The section indicates close folding, overturning and reversed faulting.

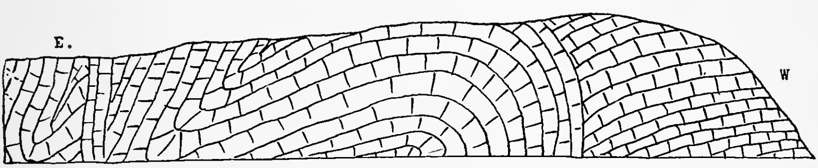


FIGURE 31.—Limestone on Hillside Street, Bennington, near J. T. Remington's.

Just south of Main street under the west bank of the cemetery the limestone dips easterly at 54° and strikes N. 31° E. One mile south of Main street, along the road leaving the latter west of Jewett Brook, near "Camp corner," in the quarry beside the road, the limestone dips 60-65° easterly, the strike in the quarry varying in a distance of 50 feet from N. 45° W. to N. 7° W. One-half mile directly south of this quarry, on the northern slope of the hill, the limestone lies quite flat. This outcrop is on the extreme northwestern slope of the hill which a mile to the southeast shows interbedded limestone and calcareous quartzite as described above, dipping 80° E. on the eastern slope and 70° W. on the northern slope.

In Bennington on Main street near the mill pond the limestone dips eastward at a low angle and shows shearing structure dipping eastward at a high angle.

South of Bennington, between South street and Dunham avenue and the Pownal road, the limestone is dove-colored, carrying many wavy bands of a chamois color, reminding the writer very strongly of certain portions of the calciferous of Dutchess

County, N. Y. The rock has every appearance of having undergone shearing whch has developed an eastward dip so that it proved very difficult to distinguish between shearing and bedding. Near the Pownal road the dove and buff seem to be clearly interbedded, dipping east so that the shearing is with the bedding, but 200 yards to the southwest the dip is 19° W. with the strike of N. 27° W. Weathered surfaces were searched for fossils without success. It was not possible from the surface exposures to determine to what extent the shearing and dip approximately coincided.

In Bennington, three-fourths of a mile west of South street, in the Lebanon Springs R. R. cut the limestone dips east with shearing joints across the bedding.

In the field north of Dunham avenue, between it and the next road north, a greatly brecciated limestone appears in numerous small and large ledges over an area several acres in extent. Plate LXXI shows the vertical face of one of these ledges. The brecciation is often coarser than that shown in the plate, but is also rather fine, the two passing into one another. The fragments range from the size of a marble to that of a man's head. The brecciation is clearly apparent on the lichen-covered surface outcrops but is most conspicuous on comparatively fresh surfaces.

Just west of the Pownal road, a few hundred yards northwest of these brecciated outcrops, the limestone strikes N. 81° W. and dips 24° southerly.

Both east and west of the Pownal road, south of Robinson's crossroads, and one mile north-northeast of Carpenter Hill, the limestone generally dips westward. One reading one-half mile south of the crossroads gave the strike N. 30° W. and dipped 48° westerly. At this place there is confusion; another reading gave a dip clearly to the southeast. The limestone is frequently brecciated, breaking into many irregular pieces under the hammer. Westward up the hill the dip is eastward.

Along the mountain road, running west of Carpenter Hill, about a mile and a fourth from Robinson's crossroad, and just beneath the eastern edge of the Mount Anthony schist, which rises very steeply here, the structure shown is exhibited in the composite section of figure 32. One-fourth of a mile northeast of this outcrop, just west of the road, the limestone shows pronounced shearing. It is the gray or dove-colored rock seen so frequently farther north, to the east of the Pownal road, and carries the same chamois-colored wavy patches and streaks.

Just south of the ledge, whose structure is shown in figure 32, the limestone of Carpenter Hill gives place to schist. On the summit of this hill the eastern margin of the schist is one-half mile farther east than along the mountain road. In both places the schist dips to the west.

PLATE LXXI.

A LEDGE OF COARSELY BRECCIATED LIMESTONE WEST OF DUNHAM AVENUE IN BENNINGTON.

Existing maps show the limestone passing over the mountain west of Carpenter Hill to join the limestone in the valley of the Hoosick. My observations find the schist intervening and contradict this connection across the mountain.

The limestone east of Carpenter Hill and southward, west of the Pownal road along the foot of the mountain to Pownal Center, so far as observed, dips westward beneath the schist. Where Jewett Brook crosses the road, and in the electric railway cut just east, the dip is apparently eastward.

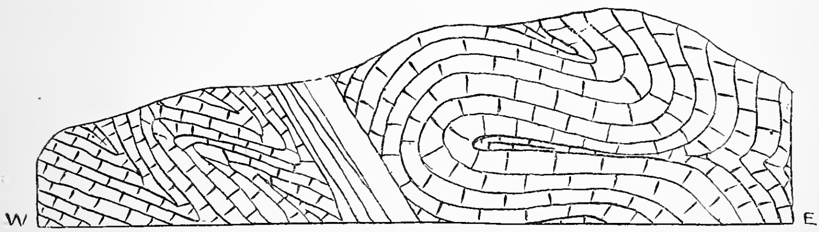


FIGURE 32.—10'-12' Limestone and schist on east side of Mount Anthony, near Carpenter Hill. Composite section.

Only a few non-committal outcrops occur southeastward on the hills as far south as the road going east from Pownal Center. On the northeastern slope of the hill lying in the angle between this road and the one going south from "Irish corner" the limestone and schist are mixed in great confusion, outcrops of one passing within short distances into those of the other, the whole side hill presenting the aspect of limestone overthrust or overfolded and resting on the schist.

Around Barber Pond and northward for a distance of three miles or more the drift conceals the limestone, leaving the structure over this broad area wholly in the dark.

It is a problem how to interpret the structure of the limestone south of Bennington, but the observations which have been noted show close folding, overturning, overthrusting, extreme and violent brecciation and shearing. I believe the limestones south of Bennington to be mainly older than those which pass beneath the schist of Mount Anthony. Studies which the writer has elsewhere made in the Taconic rocks have shown great blocks of limestone to move upward as a mass by reverse faulting against younger strata, at the same time suffering extreme folding and minor breaks within the block.

I would hesitate to assert that this is what has happened south of Bennington, but in view of the tendency to reverse faulting and the structural features observed in the field such a history does not appear improbable.

LIMESTONE AND SCHIST NORTHWEST OF BENNINGTON.

Limestone outcrops in the road and along the Walloomsac in Papermill Village and in Paran Creek along the trolley road toward North Bennington. Outcrops in Papermill Village show some minor folding westward. In the quarry east of the lumber mill on Paran Creek and a few hundred yards south of it the strike is N. 80° E. and the dip 11° S. SE. The flat position of the limestone in the bed and eastern bank of the creek, south of North Bennington, is very conspicuous.

North of the village the limestone outcrops in patches here and there. One of these is at Mattison corner and others occur a mile to the north in the fields southeast of Horton corner. Along the eastern slope of the hill at the latter locality the dip is west-northwest at one place and at another apparently northeast, forming a part of a low doming arch.

Abundant outcrops occur in the fields west and northwest of Horton's corner near "Cold Spring." A reading of the dip gave 14° NW. North of Clark's corner another reading gave the apparent dip southeast at a high angle, but at this place the rock was greatly sheared and distinction between dip and shearing was not easily made. A patch of the limestone north of "Cold Spring" showed many gray patches resembling fossils on the weathered surface. Nothing positively distinct was found and the rock was too tough to break.

The limestone formation over much of the area north of Bennington shows the same gray rock which streaks and patches of buff as described for so much of the area south of Bennington, and likewise showed evidence of much shearing.

On the west slope of the hill at Taper's corner, one and a half miles south of Shaftsbury Center, the limestone dips to the north. In the Rutland R. R. cut a mile northeast of South Shaftsbury the dip is to the south. Southeast of South Shaftsbury the dip is south or southeast.

On the southeastern slope of West Mountain the schist comes down to within a half mile of the Shaftsbury road. The southernmost outcrops of limestone just north of the road running west of Shaftsbury Center dip to the south. Along the base of the eastern slope of the mountain one-half mile farther north the dip could not be made out.

There is seen to be considerable apparent variation in the strike and dip of the limestone formation north of North Bennington. In some cases the dip may have been that of shearing structure, but in general the limestone appears to lie in gentle undulating folds and to have suffered shearing which has produced an apparent eastward dip in many cases.

North of the road at the base of the southern slope of West Mountain the schist formation succeeds the limestone dipping to the east-southeast.

In North Bennington village, one-half mile northwest of the post office, near the railroad track, slate or phyllite outcrops dipping west with eastward cleavage. A few hundred yards west are outcrops of limestone. Westward in the direction of Sodom the limestone gives place to slates.

The eastern and southern slopes of the low hill southwest of Bennington are underlain by limestone dipping to the southeast. This limestone is farther west than the slate in North Bennington village. On the western slope of the hill the limestone is succeeded by papery slates which are the southward continuation of the outcrops at Sodom.

On the south slope of the hill the limestone comes down close to Henry Bridge and continues across the Walloomsac. A half-mile southwest of the bridge the papery slates outcrop in the brook on the west side of the road dipping to the southwest with strike N. 55° W. The limestone occurs a few yards east on the east side of the road. On the east slope of the hill to the southwest of these outcrops the limestone rests on the slate.

The high hill southeast of the "ore pit" is capped by slates and flanked by limestone on the east.

The schist was thus traced along an irregular line beginning two miles west of the northern end of Mount Anthony, as shown on the map, as far north as Sodom. Another trip was planned to trace the boundary north from Sodom. There are reasons for thinking that the Vermont Report has the boundary substantially correct in representing the limestone as entirely cut off in the west by the slate just east of the state boundary.

The apparent dip of the schist up the south slope and at the summit of West Mountain is eastward. The rock at the summit is a sericite schist which does not differ essentially from that of Mann Hill both in the hand specimen and in thin section.

The country immediately southeast, east and northeast of North Bennington and northward through South Shaftsbury and Shaftsbury Center is so largely drift covered that outcrops are few and to a great extent non-committal. Limestone outcrops on the west slope, southeast of South Shaftsbury, below the slope that truncates the beds of the quartzite, with strike N. 40° E. and dip of 18° E. The limestone outcrops at a few places in the Rutland R. R. cut north of South Shaftsbury.

The outcrops on the whole through this drift-covered area suggest that the limestone is not greatly folded, as is also the case around North Bennington.

The western portion of this broad valley area northwest of Bennington is much sheared and the field observations indicate that the limestone has been pushed against and over the schist

at the west. The map shows that this limestone area has suffered at offset to the west corresponding with that in the valley quartzite north of Bennington and also with that of the Bald Mountain mass.

Throughout this broad area no marbles were found corresponding with those that pass beneath Mount Anthony and the formation was considered to belong to an older terrane than the Mount Anthony limestone.

It was hardly possible to make out the structural relations on the south and east of West Mountain. The schist of West Mountain is regarded as younger than the limestone and so also is that which the valley limestone rests against or upon at the west.

It is not possible to assert how far west the great fault that bounds Bald Mountain on the south extends in the limestone northwest of Bennington and so it is represented as dying away west of Bennington.

LIMESTONE AND SCHIST OF MT. ANTHONY SOUTHWEST AND WEST OF BENNINGTON.

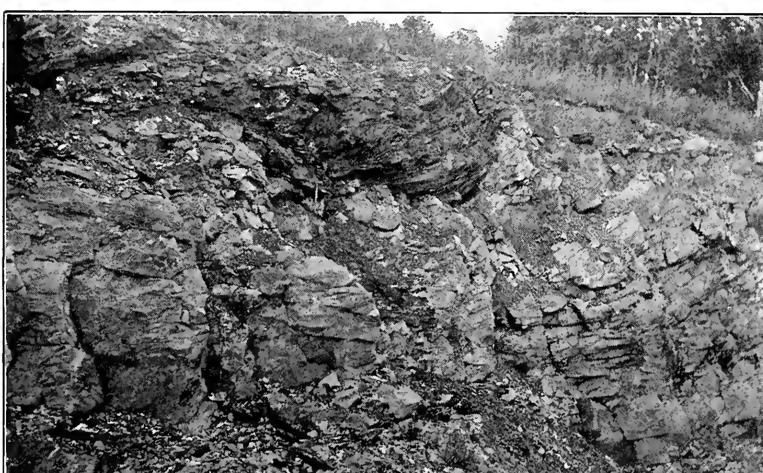
Beginning at a point about three miles south of Bennington Center near the base of the eastern slope of Mt. Anthony and proceeding northward along the slope, the limestone was found dipping westward into the mountain beneath the schist. The formation is sometimes thinly bedded, but consists mainly of beds of white or clouded marble ranging from two to three or more feet in thickness. The dip is as low as 5° in some places and always at a low or moderate angle. Towards the northern end of the mountain the dip changes to the southwest and at the northern end to due south. Southwest of Dunham's corner the limestone shows much confusion of strike and dip, the latter changing from easterly dip through a vertical position to the characteristic southwest dip. The schist near here is two or three hundred feet below its normal contour. A small normal fault has dropped the schist and disturbed the limestone.

In quarry excavations just southeast of the Edward H. Everett mansion the strike of the limestone was N. 29° W. with dip 28° S. W. Along the wood road following up the brook west of the mansion the slaty schist appears showing eastward dipping cleavage. The limestone outcrops a few yards north on nearly the same contour. Farther up the mountain in the woods at an old quarry the schist rests conformably on blue limestone which strikes N. 80° W. and dips 47° southerly.

Along the edge of the woods northwest of the Everett mansion the limestone varies in strike between due east and west and N. 48° W. Along the northwestern slope a short distance up from the base the rock is a thick-bedded marble. Along the northern slope just below the woods these heavy beds dip south-

PLATE LXXII.

A. BLUE CRYSTALLINE LIMESTONE BENEATH MT. ANTHONY SCHIST AT COLGATE'S QUARRY. THE ROCK IS USED FOR ROAD METAL.



B. CONFORMABLE SCHIST AND LIMESTONE JUST SOUTH OF OUTCROP IN PLATE VI.

ward and this same dip appears along the Pownal road from Bennington Center just west of the brecciated ledges which were described above and also along the road running east and west through Bennington Center.

A private road ascends the northwest slope of Mount Anthony on the estate of James C. Colgate. Along this road the limestone gives place to the schist which strikes N. 50° E. and dips 20° easterly. In some slaty beds in this schist some distance up the road a crushed crinoid stem was found.

Along the road to North Pownal, which branches from the Bennington-Hoosick road on the west side of Mount Anthony, the dip of the limestone is southerly. In a quarry used for road metal, about a mile south of the Bennington-Hoosick road, a blue limestone with the same southerly dip conformably underlies the schist (see Plates LXXII, A, and LXXII, B). The conditions are similar to those in the quarry in the woods west of the Everett mansion.

In Bennington Center, three-fourths of a mile northwest of the monument, the limestone was observed with the same southerly dip.

Along the North Pownal road, from the quarry south of Colgate, only the schist formation outcrops to within a mile of North Pownal village. The western slope of Mount Anthony is schist and this was followed over the ridge to Carpenter Hill. If, as seems likely, there is a fault on the northwest of Mount Anthony it dies away southward.

Mount Anthony is a synclinal pitching southward and capped by the schist formation which is conformably underlain by blue crystalline limestone and heavy-bedded marble which outcrop on the northwest, north, northeast and a part of the east slopes of the mountain.

THE LIMESTONE AND SCHIST IN NORTH POWNAL AND POWNAL VILLAGES.

Northeast and east of North Pownal village is a large inlier of limestone, as shown on the map. It extends east of North Pownal as far as the road running south from Arnold's (school house) corner along which it is mixed with the slate as far as the next corner south. This inlier is surrounded by the slate or schist on the west, north and east and at the south extends along the valley of the Hoosick as far as Pownal. South of Pownal it seems to be cut off by the schist from the limestone northwest of Williamstown.

At the northern end of this inlier, east of the road from Bennington Center to North Pownal, the limestone forms a conspicuous hill. A reading here gave the strike N. 35° E. and the dip 23° SE. Across the road at the "Wash Tubs" (see plate

LXXIII) the limestone arches gently as shown in figure 33. At this place the stream has cut into the gently arching limestone and made a series of large pot-holes locally known as the "Wash Tubs."

In the old quarry at Whipple's corner in North Pownal village the limestone is rather massive. In the north wall a small overturned fold was observed, the axial plane lying flat. In the south wall the dip appeared to be gently westward, but dynamic movement has largely effaced distinct bedding.

East of Main street in the village the limestone forms a high scarp to a point one-half mile south of the railway station. At the quarry at North Pownal station the limestone shows folding on large and small scales with severe jamming. In the railroad bank just under the highway, southwest of the quarry, is the slate which is greatly jammed and crushed. Just across the river opposite the quarry the slate or phyllite forms a knoll between the river and the road near the Dean place. Here the slate shows severe crumpling which dips eastward.

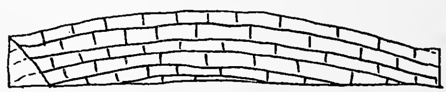


FIGURE 33.—Limestone structure at Wash Tubs.

Southward along the west bank of the stream a thick drift covering conceals the rock near the river, but schist outcrops up the slope of the hill to the west. A mile south from the Greylock Mills, on the west side of the stream, a knoll of limestone lies close to the river clearly resting on or against the slates. South of this outcrop past the abandoned Service farmhouse all is slate nearly to Daniel Gardner's house.

Along the road south from the Service house, just after it makes its turn west of Gardner's house, the slate outcrops in the road and the brook with limestone in close proximity. The actual contact was not seen but the two are less than eight feet apart. Limestone outcrops south of the road and elsewhere partly surrounding the slate, indicating that the limestone has been pushed over on the slate.

At the bridge in Pownal limestone outcrops in the bed of the river.

Along the road west of the Hoosick, south of Pownal, the drift hides the underlying rock, but near the quadrangle boundary, a half mile east of the road, near the railroad bridge, the schist outcrops in numerous ledges dipping west into the hill. Westward the schist passes beneath the drift of an immense drumlin. It forms the west bank of the river south of the railroad bridge, but east of the river is succeeded by limestone.

PLATE LXXIII.

THE WASH TUBS, NORTH POWNAL.

In thin section this schist shows a felt work of sericite with quartz and some magnetite as accessory and numerous flakes of chlorite rather uniformly distributed in the section. In correspondence with the presence of the latter the hand specimen shows a greenish color, although the parting planes show the same silvery luster exhibited by the schist of Mann Hill.

On the map, between the railroad bridge and Pownal, the schist of Mason Hill is made continuous with that west of the river. The schist was traced along the Pownal road east of the Hoosick to and through the village of Pownal to a point about one mile south of North Pownal station, where it is succeeded by the high scarp of limestone along the road. At this point the boundary turns northeastward and passes west of the brook to the mixed outcrops of schist and limestone that have been described.

All along the Pownal road at the base of the westerly slope of Mason and Mann hills, the dip of the schist is eastward, while west of the river, so far as observed, it is normally westward.

The eastern margin of the limestone hill east of North Pownal shows pronounced shearing, especially about one mile north of Wright Bridge corner, just west of the brook. It is here a gray rock with chamois-colored stringers and patches like that so common north and south of Bennington. Although the limestone in the quarries in North Pownal is somewhat different, in the surface outcrops near by, it weathers in a similar way. I have not found in this inlier any heavy beds of marble like those on the east and north slopes of Mount Anthony.

I look upon this limestone at North Pownal as a faulted inlier which is thrust against or on the slates at the west and which pinches out southward in Pownal village.

SCHIST OF MANN HILL.

Through the fields and along the road from North Pownal northeastward to Carpenter Hill and eastward to Pownal Center are numerous outcrops of the schist dipping east. Along the eastern margin of the Mount Anthony ridge north of Pownal Center the dip is westward into the hill. There is, therefore, within a mile going south, a change in dip from west to east. All the schist south of the road from Pownal Center to North Pownal and along the road, as described above, from Pownal to North Pownal, and on the west slope and summit of Mann Hill dips east. On the east slope of Mann Hill the schist also dips east and passes beneath the limestone which is mixed with the schist in great confusion south of "Irish corner" as described above.

The schist of Mann Hill has been overturned, and the limestone east of it has been either thrust or overturned on it.

The rock at the summit of Mann Hill is a silvery sericite schist. In thin section it shows a felt work of sericite with quartz and without apparent accessories.

THE SCHIST AND LIMESTONE OF MASON HILL.

The summit and western slope of Mason Hill are underlain by schist similar to that of Mann Hill. Along the road over the summit it is noticeably crumpled.

The modified drift is piled high against the southwestern slope of Mason Hill above the Hoosick River. Limestone outcrops from beneath the drift along the Williamstown-Pownal road a hundred yards southeast of the railroad bridge.

A road ascends the hill one-fourth of a mile south of this outcrop. Four or five hundred yards north of this road just above the gravel pits limestone lies on the sericite schist as shown in figure 34. The limestone continues up the hill northward

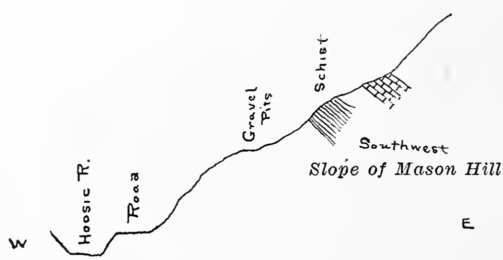


FIGURE 34.—Limestone and schist.

along the slope and is succeeded by the schist, both dipping easterly. Here again the limestone rests on the schist.

East of the road over Mason Hill the schist outcrops under the west bank of Reservoir Brook and just across the brook less than 50 feet away rises the high scarp of compact, white quartzite. The schist along Reservoir Brook is greatly shattered. This broken schist was also found east of Meyer's house along the road and at this place lies close to the northward extension of the fault along Reservoir Brook.

Along the Pownal road towards Williamstown the limestone outcrops along the east side of the road with southeasterly dip and strike N. 18° E., and southward joins the limestone area of Williamstown.

The Hoosick between the Massachusetts line and North Pownal has apparently availed itself of a great line of rupture. Along this break the limestone has come to the surface, as now exposed, except in the interval between Pownal and the railroad bridge two miles southeast of the village along which the schist of Mason Hill apparently joins that west of the river.

GENERAL RELATIONS.

It is difficult to represent on the map the probable intricate structural relations of the rocks of the area. The writer hoped by another season's work to get some light on the relative ages of the rocks which in so many cases apparently lie in faulted positions against each other.

It is possible that the major flexures which ultimately were to find expression in the Green Mountain elevation began early in the Cambrian period and that folding went on slowly enough to allow for continuous deposition from Lower Cambrian to Ordovician. The writer has elsewhere suggested that faulting and erosion may possibly account for the apparent absence of portions of the Cambrian.

The thick masses of sediments which accumulated in the great troughs of the older rocks underwent profound folding as the basement crystalline floor slowly closed in on them. They were often greatly jammed, overturned and sheared. It would seem that after a time the pre-Cambrian floor reached the limit of strain and broke into blocks which were thrust upward into the younger rocks, but not in all cases reaching the surface, as now exposed. The folded younger rocks were caught at whatever stage of folding they had reached when the gneissic floor broke.

Later adjustment faulting would have probably caused some slumps along the planes of earlier reverse faulting.

Similar relations obtain in other portions of the Taconic belt; as at Rutland, Vermont, and in Dutchess County, N. Y. at Stissing Mountain, near Stissing Junction, at East and Schaghticoke mountains near Dover Plains, at Corbin Hill near Pawling, in the Fishkill Mountains and also at "Pine Island" near Patterson, in Putnam County.

The great abyssmal swell of the pre-Cambrian floor caused it to break at numerous places, often pushing the gneiss up into much younger strata, the gneiss often carrying the quartzite with it. Movements of lesser violence would have caused similar breaks between younger rocks which would not be so apparent as where the movement was violent enough to carry the pre-Cambrian against the Ordovician limestone and schist.

THE PLEISTOCENE.

Only incidental attention was given to the surface deposits.

Typical kame moraine topography prevails over the area around Barber Pond and two miles north of it. (See Plate LXXIV, A). Barber Pond is very shallow and is surrounded and formed by kames. A tongue of ice probably projected down the valley from Bennington and the drainage from this tongue was impounded in a shallow basin formed by Mann and Mason hills

on the south and the ice on the north. In this basin the kames were built. They are the marginal moraine deposits of the ice in the valley.

Northeast of Barber Pond a long serpentine ridge rises gradually from the flat ground just west of Brown's corner and extends one-fourth mile up the hill in a northeasterly direction towards the range. It has the form of a typical esker and was probably formed when the ice rested on the lower slope at the foot of the range. (See Plate LXXIV, B).

There is evidence of border drainage along the eastern edge of the valley southeast of Bennington.

East of Bennington the Walloomsac has cut through a thick bench of gravel and sand which the stream built out towards the ice margin as it receded from the range. This delta terrace extends for two miles southward west of Harmon Hill. At the time it was forming the drainage of the Walloomsac may for a time have passed as a marginal stream along the eastern edge of the ice and around its southern end to find exit at the pass at Pownal Center.

On the southern flank of Mason Hill the modified drift, which is piled high above the river, consists of thick deposits of well-sorted sands and gravels and probably represents deposits from glacial streams into a lake at the south during a halt of the ice in its retreat northwest along the Hoosick Valley.

North of Bennington the typical knob and basin topography is lacking. One or two kames were noted on the southern end of West Mountain.

STUDIES IN THE GEOLOGY OF WESTERN VERMONT

CLARENCE E. GORDON, Ph. D.
Professor of Geology, Massachusetts Agricultural College

From the Twelfth Report, Vermont State Geologist

tracks at Chester Depot and is equipped with Raymond crushing machinery, etc.

In spite of the general car shortage, Vermont talc companies report no difficulty in moving their products.

The American Soapstone Finish Company, Chester Depot.—C. P. Dodge, sole owner; E. E. Holt, superintendent.

This company mines a low grade talc from the Carleton Quarry, in Chester, and makes it into a variety of substances: plaster board, soapstone finish, dusting powder for tires, etc. It also sells its product to the roofing and paper trade.

SOAPSTONE.

As already stated, the soapstone industry in Vermont has been at a standstill for several years, although this substance is by no means exhausted.

Recently the Steatite Electric Products Corporation, of Yorktown Heights, N. Y., has been formed for the manufacture of a new electric flatiron, the core of which will be made of soapstone. It is understood that this corporation has leased the old Union Soapstone Company's properties and will supply itself with soapstone from them.

STUDIES IN THE GEOLOGY OF WESTERN VERMONT.

Clarence E. Gordon,
Massachusetts Agricultural College.

TABLE OF CONTENTS.

INTRODUCTION.

General. The writer's studies among the rocks of the Taconic region were begun in the summer of 1906 in Dutchess County, N. Y.[1] and were continued intermittently for several seasons, first in the Hudson valley around Poughkeepsie and later eastward into the Dover-Pawling valley and the hills that bound it east and west. The area at the east proved so complex that it appeared advisable to examine other portions of the Taconic belt before suggesting any interpretations of the geological structure.

In the summer of 1912 an examination was begun of the southwestern portion of the State of Vermont, in Bennington County. Although only about three weeks were spent in this region a number of interesting observations were made, and because it did not appear practicable to continue the work with the idea of mapping a quadrangle, the results obtained were published in the Report of the Vermont State Geologist in the form of notes on the geology in the vicinity of Bennington.[2] The work around Bennington, although hardly more than started, opened up many problems and served as a stimulus to further studies in western Vermont which it is the object of this paper to describe. These later studies were undertaken with the kind consent of the State Geologist.

The field studies on which this paper is based were made in part in the summer of 1918 during a three weeks' trip on foot through the Vermont valley and portions of the Champlain lowland, from Bennington at the south as far north as Vergennes, with occasional trips into the mountains which hem in the valley on each side and bound the Champlain lowland on the east. Very brief examination was also made during the same season of the formations around Burlington and along the lake shore at Malletts and St. Albans bays. This trip was cut short by an attack of influenza. During parts of the next two summers more detailed studies were made in the towns of Pittsford, Chittenden, Brandon, Leicester, Whiting, Shoreham, Sudbury, Orwell, Benson and Hubbardton. In addition the writer was able in the season of 1920 to inspect with care portions of the formations on Grand Isle, both alone and in company with the State Geologist, and to review some of the relations in the vicinity of Bennington. In the season of 1918 it was hoped to make a more thorough study of the rocks within the slate belt and also in the Green Mountain plateau than circumstances permitted.

In all the work it was the practice to inspect as many outcrops as possible, but especially in connection with the studies in Brandon, Sudbury and Orwell, which was a region selected in

[1] Geology of the Poughkeepsie Quadrangle, N. Y. State Mus. Bull. 148, 1911.

[2] Ninth Report of the State Geologist, pp. 337-370.

which to make a wide surface section from the Green Mountains to Lake Champlain. The real purpose in mind of getting a first-hand knowledge of some of the important field relations shown by certain formations and their members under various aspects of deformation and erosion at widely separated places made it advisable to give a discursive but critical examination to a rather extensive region.

Brief historical statement. To most people the rocks of Vermont are known because of the great quarries of marble and slate which have been opened in them and from the excellent descriptions which have been given of these valuable assets of the State. To geological students the part played by Vermont rocks in the annals of American geology has become known and appreciated through the work of many geologists, among whom may especially be named that keen, patient and tireless investigator, Rev. Augustus Wing. Vermont rocks also played a part in the controversy which grew out of the diverse interpretations made by different students in efforts to unravel the difficult stratigraphy and structure of the Taconic region. The great controversy has passed into history and most of the reverberations of its acrimony have died away; but many differences of opinion have persisted and probably always will. These and the controversy itself have served useful ends in directing attention to a region of much interest and importance in the geology of eastern North America.

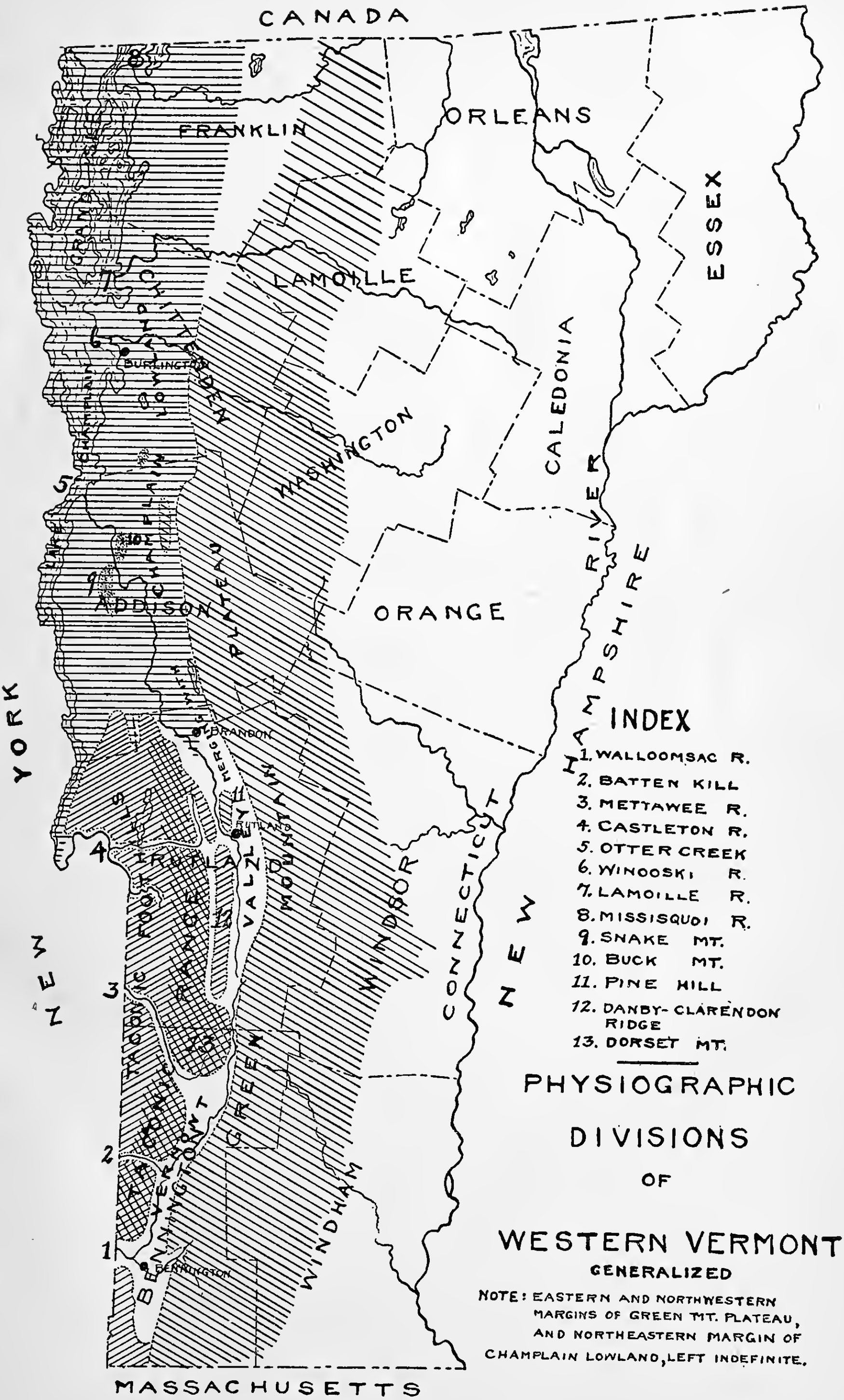
In the end probably all will have to subscribe to what Elkanah Billings wrote as long ago as 1872, that, on account of the extremely complicated structure of the rocks, no man living (and one might add, or those who are to come) would ever see a perfect map of the Taconic region. Nevertheless, towards that end the workers of future generations will continue to go forward.

General plan of the paper. The paper is divided into two somewhat distinct and yet closely correlated parts:

1. (a) The description of the principal physiographic divisions of western Vermont;
   (b) An account, accompanied by brief descriptions, of the characters, distribution and other features of the various formations with which the paper deals.
2. (a) The description and discussion of a number of observations made by the writer in various parts of western Vermont, particularly with reference to the secondary deformations of the different rocks;
   (b) Conclusions reached or interpretations suggested by the writer.

A part of the program is avowedly an ambitious one. It should be stated that any interpretations which are offered are advanced with a full appreciation of the difficult geology involved and of the achievements and contributions of others who have labored to solve the problems of the region.

PLATE XXI.


CANADA
FRANKLIN
ORLEANS
ESSEX
LAMOILLE
CHITTENDEN
BURLINGTON
CALEDONIA
WASHINGTON
ADDISON
ORANGE
RIVER
NEW HAMPSHIRE
YORK
NEW
BRANDON
RUTLAND
WINDSOR
CONNECTICUT
NEW
WINDHAM
BENNINGTON
MASSACHUSETTS
INDEX
1. WALLOOMSAC R.
2. BATTEN KILL
3. METTAWEE R.
4. CASTLETON R.
5. OTTER CREEK
6. WINOOSKI R.
7. LAMOILLE R.
8. MISSISQUOI R.
9. SNAKE MT.
10. BUCK MT.
11. PINE HILL
12. DANBY-CLARENDON RIDGE
13. DORSET MT.
PHYSIOGRAPHIC DIVISIONS OF WESTERN VERMONT
GENERALIZED
NOTE: EASTERN AND NORTHWESTERN MARGINS OF GREEN MT. PLATEAU, AND NORTHEASTERN MARGIN OF CHAMPLAIN LOWLAND, LEFT INDEFINITE.

PHYSIOGRAPHY.

General. Mention has been made of certain physiographic features of Vermont which for the general reader require a somewhat further brief description. The natural relief features and to some extent the political boundaries of a region are landmarks which form the framework on which one hangs, in the form of maps and otherwise, the description and account of the geological features. A map is therefore offered to show the principal physiographic divisions of western Vermont. This map may be useful in conveying some idea of the present lay of the land. It has, however, many limitations in following any but the most recent geological processes. If the present land forms and surface conditions are too narrowly followed they may become a source of embarrassment in interpreting the true geological history.

For the purposes of the paper four physiographic divisions are recognized. The discussion of the geology is inevitably developed about these divisions. As explained above, personal observations have not been made with equal thoroughness over all four divisions.

1. The Green Mountain Plateau and Its Ranges.
2. The Vermont Valley.
3. The Taconic Range and Its Foothills.
4. The Champlain Lowland.

GREEN MOUNTAIN PLATEAU AND ITS RANGES.

This prominent physiographic division from which Vermont has derived its name, is a broad upland which extends as a wide region lengthwise across the State from north to south. It crosses Massachusetts and its counterpart forms the highlands of western Connecticut, southeastern New York and New Jersey and may be traced to Pennsylvania and beyond. Northward it passes into the Province of Quebec. The western portion of this division which extends from New Jersey northward into Canada was designated by Dana[1] as the "protaxis" of the Appalachian chain, which extends from Alabama to Canada.

In their present development the Green Mountains form an elevated plateau throughout their extent. In Vermont the plateau is already deeply trenched by some rivers, particularly in its northern part, and more or less incised by tributary and other streams. On the whole its rugged outlines give it a youthful aspect, which may be attributed in part to the resistant character of its rocks.

Generally speaking, the surface is broadly undulating and averages roughly about 2,000 feet above sea-level. There are numerous rather broad areas about 500 feet higher, and numerous peaks and ridges rising to and above 3,000 feet. Mt. Mansfield, the highest elevation, is 4,406 feet high. The sharper elevations

[1] Manual, Fourth Edition, p. 24.

which may be thought of as the more distinctly ridge-like elements of the plateau, in the northern part of the State form two rather distinct ranges which merge into one in the southern half.

The highest peaks of the State are all only a few miles distant from the western edge and succeed one another along a line that suggests a prominent general structural axis which rather closely parallels the western margin of the plateau. This margin is marked for long reaches by a prominent scarp or by a series of cliffs. It begins in Pownal in Bennington County and follows a north-northeast direction to the northeastern part of Manchester township and thence has a general northerly direction to about the latitude of Pittsford. Then it bends slightly to west of north and is sharply distinct as far north as Monkton. North of Monkton it appears more broken in character, but a general return to a north by east course can be discerned. The margin as thus described has embayments at places from Pownal northward. The structural and physiographic axes often have suggestive coincidence, although there are variations whose import is not clear.

While generally well settled and intersected by roads, some of which cross the plateau into the valley at the west, there is a wide strip along the western portion, from the Massachusetts boundary northward two-thirds the way across the State, which has only a few roads and is still mostly a wilderness.

THE VERMONT VALLEY.

Directly west of the Green Mountain plateau, and extending from Pownal to Brandon, lies the "Valley of Vermont." The topographic break between the two divisions is generally abrupt. The western margin of the plateau upland is usually bold, often precipitous. The streams which come down from it to the valley have not strongly impressed their drainage upon the plateau.

In its present topographic stage of development this division is only a relative lowland between the Green Mountains on the east and the rugged Taconic range on the west. In its southern part the lowest contours are 540 feet along the Walloomsac River near Bennington, and 620 feet along the Batten Kill at Arlington. Along the course of Otter Creek from Danby northward the contours descend from 660 feet to 340 feet near Brandon, where the Vermont valley merges with the Champlain lowland.

The floor of the valley is in fact almost throughout a moderate upland which is obscured by the higher lands which hem it in. It is mostly uneven and studded with hills. The average relief is probably above 800 feet. The valley form is not, as one unacquainted with it might infer, such as would have been produced by a single master river running through it.

North and south of Bennington, around the head streams of the Walloomsac River, this division is about six miles wide. To the west along the river it passes by a broad gap into the Hudson valley lowland. At Bennington the Vermont valley is offset two miles to the east and in Pownal is completely intercepted by the Mount Anthony-Mason Hill ridge. Towards the north in Sunderland it narrows to a width of two miles. It widens again near Manchester around the head streams of the Batten Kill and the Mettawee. North of Manchester it is interrupted by Dorset Mountain and here is about one-fourth of a mile wide. North of Dorset Mountain the major valley is broken into minor ones by prominent intermediate ridges. Otter Creek occupies the eastern minor valley, which from Wallingford to Rutland is over three miles wide. As the topographic map shows the creek changes direction at Rutland from north to west, crossing the structural axes of the rock formations; but at Center Rutland the stream regains a general northerly direction and flows through a narrow valley to Proctor. Thence it passes into the open valley of Pittsford which leads into Brandon. In Brandon the major valley has a more uniform surface and widens out northward to form the Champlain lowland.

The Vermont valley has its physiographic, and to a considerable extent also its geological, counterpart in the Berkshire valley of western Massachusetts along the upper reaches of the Hoosic and Housatonic rivers. There is a recognizable apparent similarity in general configuration between the two, and in the modifications occasioned by hills, ridges and outlying masses of the other physiographic divisions.

The Berkshire valley continues into Connecticut, but at Canaan the Housatonic leaves a wide valley for a narrow one across the upland, which in Connecticut, however, has a lower average elevation than in Massachusetts and Vermont. In northwestern Connecticut and southeastern New York irregularities appear consequent upon the geological structure and relations there present.

THE TACONIC RANGE AND ITS FOOTHILLS.

The Taconic range bounds the Vermont valley on the west throughout its length, except for erosion gaps, the widest of which is west of Bennington. In Vermont this division is the continuation of a similar range that lies along the border between Massachusetts and New York. It extends in Vermont from Shaftsbury in the southwestern part of the State to Orwell and Sudbury. North of Pownal practically all the range is in Vermont and all the higher summits are in this State. Viewed as a broad unit the range overlaps the New York-Vermont boundary in its southern half. North of Rupert the western margin hugs

the State line as far as Poultney, whence it passes due north to Orwell and Sudbury.

In its course across Vermont the relation of the range to the Vermont valley is marked by at least two prominent structural irregularities. Southwest of Bennington, in correspondence with offset in the Vermont valley already mentioned, Mt. Anthony lies farther east than does West Mountain in Shaftsbury, and in the town of Dorset the mass of Dorset Mountain rises abruptly in the valley midway in its course from Bennington to Brandon.

The higher elevations of this division range from about 2,500 feet to about 3,500 feet above sea-level. Equinox Mountain reaches 3,816 feet and Dorset Peak is 3,804 feet high. Most of the higher summits lie along the eastern border of the range. West and north the surface falls off in elevation into the foothill region; but many scarps and precipices marking probable fault lines greatly disturb the surface regularity and contribute notably to the present topographic outlines. Although symmetry of contours is therefore lacking in the present stages of topographic development if one were to generalize very broadly the northern and western slopes of the division, the erosion features of the elevation would fall off gradually westward and northward by slopes of similar gradient to the relative lowlands of the Hudson and Champlain valleys.

This division is cut across and otherwise by streams whose branches heading rather deeply into it have dissected it into a series of peaks and ridges. In its outlines the division offers some contrasts with western edge of the Green Mountain plateau; but stream incision has not been pronounced in either wall of the valley and the topographic outlines of its two slopes wear much the same expression for long distances.

The valleys which cut through the range mark the extension of the lower Hudson valley levels into the intermediate upland of the Vermont valley. There are certain notable differences among these valleys which may be mentioned here. The valley of the Walloomsac River is wide and is really a broad extension of the Vermont valley westward. That of the Batten Kill is narrower and hemmed in by steeper slopes. The valley formed by the Mettawee and the West Branch of the Batten Kill is fairly wide and the bottom lands are well developed. The valley of Castleton River is rather narrow and its northern are steeper than its southern slopes, as nearly all its branches within the range come in from the south.

THE CHAMPLAIN LOWLAND.

The distinctness of this physiographic division as a whole is sharper when viewed from a distance in broad sweeps rather than from a close examination of the topography of its surface, which, like that of the Vermont valley is studded, in some places

more than in others, with hills. It may first be described in its larger outlines.

Lake Champlain lies along its western border, and rising from the western side of the lake, with their bases dipping into it at places or separated from the lake shore by a narrow strip of hilly land, stand the rugged Adirondacks. In its southwestern portion it is bounded by the northwestern foothills of the Taconic range. The boundary at the southwest swings eastward around the Orwell hills and then encloses a narrow embayment extending up the valley of the Lemon Fair River between the Orwell and Sudbury hills. It then passes around the northern end of the Sudbury hills to Brandon and thence northerly along the western base of the Green Mountain plateau, with the topographic break sharply outlined between the lowland and the plateau as far north as Monkton. North of Monkton the Green Mountain plateau surface is more broken along the edge; but the higher average relief is well enough preserved to give an outline to the Champlain valley in its extension northeastward to the Canada line. At the north the Champlain lowland merges with the St. Lawrence valley. At the south along the narrow region of the lake it joins with the Hudson valley.

The lowest surface in this division is that of Lake Champlain, which for high and low water conditions averages about 100 feet above sea-level. But the lake occupies a depression, the actual depth of whose rock bottom will probably never be known, as it could hardly have escaped being modified by glacial deposits. Soundings have shown that the waters now fill a basin of varying depth and bring out in the channel-like character of its western portion the indication of former stream erosion. The maximum depth reached is about 400 feet near Essex, N. Y., but the present bottom ranges from that depth to comparatively shallow water. The bottom of the lake in many places thus stands in marked contrast with even the lowest portion of the present exposed surface of this lowland. The lake has many low islands of varying dimensions throughout its extent.

Between Lake Champlain on the west and the Green Mountains on the east for a distance of about 40 miles from the northern end of the Taconic range to Burlington, converging somewhat towards Burlington, and again north of Georgia through St. Albans and Highgate to the Canada line, a large portion of the surface ranges from about 100 feet at the lake to 350 feet inland, with the rest of it from 350 to over 400 feet. Along parts of the Otter Creek valley and along the lake for a width of about six miles, in the areas just described, the contours are relatively

Township Map of Vermont.

widely spaced and run long distances without closing. There is distinguishable a low range of hills extending north from Orwell, which is so reduced over most of its surface as hardly to deserve the name, but which is noticeable by reason of the lower land along the lake and from the excavation of Otter Creek on the east. This range reaches its greatest altitude in Snake Mountain (1,271 feet) and terminates in Buck Mountain (927 feet) south of Vergennes. Mt. Philo in Charlotte is 968 feet high. In Bristol and Monkton there are prominent hills including Hogback (1,220 feet), and several conspicuous hills occur west and north of Lake Dunmore. St. Albans Hill (910 feet) and Aldis Hill (840 feet) are the conspicuous elevations north of Georgia. The Orwell-Buck Mountain ridge at the south merges topographically with the western foothills of the Taconic range.

In late Pleistocene time much of the Champlain lowland was covered probably by the waters of the sea which probably extended into the Vermont valley as far south as Rutland. The present surface, both on the islands of the lake and on the mainland, gives clear evidence of the former submergence of a wide portion of this lowland by an inland water body.

North of the Winooski River to the latitude of Georgia the surface has a more uniform and a uniformly higher elevation, ranging from 300 to 350 feet. The contours are more narrowly spaced and close within short distances, giving a more cut-up topography.

Four streams, Otter Creek, and the Winooski, Lamoille and Missisquoi rivers, cross the lowland to enter Lake Champlain.

REVIEW OF THE GEOLOGICAL TERRANES AND FORMATIONS OF WESTERN VERMONT AND THEIR DISTRIBUTION.

General remarks. A short acquaintance with the rocks of western Vermont in their field relations will soon convince one that they have had a long and varied history, that their present geography is very different from that which existed at various times in the past, and that many of them are now remote from the positions which they once occupied.

The general geology of areas contiguous to Vermont and extending for some distance north and south of the State shows that while the Vermont rocks have had in some ways an independent history they are in a broad way genetically related in age and perhaps quite as much so in certain general structural characters to rock formations over an extensive region.

It is more or less widely recognized that many similarities in the age and structural relations of the rocks over this wide region permit a certain amount of generalization with regard to broad crustal movements concerned in their deposition. Account has been taken of great tectonic displacements which are known

to have occured, in explaining the absence of certain strata, or better perhaps certain faunas, over the entire region and the apparent limitations of others; but these phenomena have also been explained, at least in part, on the basis of minor crustal movements which have operated to cut off faunal provinces from each other and to restrict the areas of continental seas.

As investigations have extended our information concerning details of stratigraphy we have had positive confirmation of the wide extension of certain ancient seas within the region. On the other hand extensive study has failed to reveal any conclusive evidence of the former presence of certain seas, which are generally assumed to have been wholly absent, or the wider extension of others, whose faunas are present in places, and whose ancient boundaries are set on the basis of known outcrops.

From the nature of the complex geological relations now present the explanations of these absent intervals cannot be based upon positively identified depositional unconformities between younger and older rocks than those which are absent. It is, of course, necessary to recognize the possible existence of erosion intervals of varying degrees of duration among sedimentary formations, due to periods of restlessness of the internal forces which disturb the crust, but one must also consider the evidence that the crust may apparently remain relatively quiet for immense intervals of time, and particularly, for the region of western Vermont and related areas, it is necessary to take account of the evidence of profound crustal displacements and metamorphism, and of erosion at various periods of the region's history.

It has not been clear just how far it would be well to go for the profit of the general reader as well as for the more precise information of the geological student in reviewing the characters, variations and distribution of the different terranes and formations of the region under discussion. It is clear that some idea of these different rocks and the confusion that prevails among them in the field should be given as an aid to the discussion that will follow.

A categorical statement of such matters is likely to leave an impression of simplicity; but care will be taken in the sequel to point out the many difficulties that lie in the way of positive determinations of field relations and that conclusions are based on what seems most probable, with the evidence at hand, among several possibilities that are presented.

The following descriptions are purposely given with considerable fullness, but structural considerations are largely postponed for later treatment.

PRE-CAMBRIAN.

According to many observers the pre-Cambrian basement, or old sea floor, on which the Lower Cambrian rocks of this general region were deposited, is decisively exposed at various places

in the Green Mountain plateau. The rocks which have been described as pre-Cambrian consist of gneisses, which are notably chiefly of probably igneous origin, and other rocks such as schists, quartzites, graywackes and crystalline limestones.

The discrimination of the pre-Cambrian is most satisfactory in those places at which a heavy basal quartzite, or a conglomerate, appears to rest unconformably upon, or to be separated by a thin, schistose layer from a rock whose structural features are in pronounced discordance with those of the younger rock, and are apparently of much more ancient date. In Massachusetts and New York similar relations have been described and seem to leave no doubt of the exposure at the present surface of a pre-Cambrian core in the Green Mountains. That certain old gneisses antedated the Cambrian and formed its floor of deposition is substantially borne out by numerous localities where the advancing Cambrian sea caught and preserved portions of the regolith of the land which it was overlapping. The more or less decayed material seems to have been only partially sorted at times and seems to have taken on in greater or less degree the bedded structure of the Cambrian while grading at depth into less altered rock which retained more or less of the structure of the parent gneiss. Such relations seem especially significant with respect to the question of depositional unconformity in a region that gives evidence of more than one orogenic movement and of profound overthrusting; for it is conceivable that contacts of pure quartzite, or even conglomerate, could in such a region be the results of other processes than marine overlap. It will be noted later also that there are numerous places in western Vermont where Ordovician limestones apparently rest by unconformity on rock that appears to be Cambrian without any traces of a basal transgressive sand or other rock intervening.

The separation of the Vermont pre-Cambrian into systems such as have been recognized elsewhere is a task which has yet to be worked out for the Green Mountain plateau generally. In various parts of the plateau Whittle, Keith and others have described as probably pre-Cambrian various metamorphic rocks such as quartzite, schists and crystalline limestones which have been called Algonkian, Huronian and so forth. Similar rocks have been described for Massachusetts, New York and Quebec. The discrimination of older rocks from altered Paleozoic has not always been made with a sharpness that is conclusive.

While there is, generally speaking, an abrupt passage from the less metamorphosed rocks of western Vermont to those of the plateau this fact by itself is discounted somewhat by the undoubted upthrust or overthrust relation of the plateau to the rocks at the west of it. It is somewhat significant, although exhaustive search has yet to be made, that in northwestern Vermont no pre-

Cambrian basement contacts have yet been discovered to the Paleozoic rocks.

In spite of metamorphism and apparent absence of fossils, investigations have already extended the range of Paleozoic seas over this region, although it remains to show that in some cases these were the same seas that laid down the rocks of what is now western Vermont.

In western Massachusetts Professor Emerson early suggested a separation of the pre-Cambrian, and in early descriptions of certain rocks he used the term Algonkian. Coming in later years apparently to a more conservative view he called the pre-Cambrian rocks of western Massachusetts, Archaean, and the Green Mountain plateau a "broad Archaean-Silurian upland."

The basal Cambrian quartzite has been found some distance eastward from the western outcrops of the gneisses in Vermont, Massachusetts and elsewhere where it has been preserved by down-folding or down-faulting as erosion outliers. The quartzite or its probable equivalent extends for miles as a fringe along the western margin of the plateau. Throughout the ages-long history of these rocks we may believe it has in some way been protected from erosion. It is plausible that conditions were not favorable for the preservation of vast areas of Cambrian beds, and possibly also later ones, elsewhere in what is now the plateau.

West of the Green Mountains presumably the pre-Cambrian extends at unknown depth beneath the rocks now present at the surface.

CAMBRIAN.

Lower Cambrian.

The Lower Cambrian has been described as represented in Vermont by the following-named formations:

1. "Vermont Formation."
2. Dolomite and a quartzite-dolomite interbedded series.
3. "Red Sandrock."
4. "Georgia Slates" ("Georgia Group").
5. "Roofing Slates" (with associated rocks).

Parts of all these formations were presumably contemporaneous and lithological differences were presumably due to different conditions of deposition. Certain members of the Vermont Formation can be reasonably shown to be basal and conformable to the dolomite. The interbedded series in some places lies on the dolomite and this seems to be the normal succession. There has been so much disturbance of the region that the present relations are sometimes obscure. In some places the interbedded series apparently lies on quartzite of the Vermont Formation. The Red Sandrock has been described as conformably subjacent to the Georgia Slates in northwestern Vermont. As indicated above the base of the Vermont Formation and its pre-Cambrian

contact has been fairly conclusively demonstrated; but the depositional bases of the Red Sandrock and the Roofing Slates are unknown.

Each formation presents horizontal differences which are better shown in some than in others. In all cases the intrarelationships and the relations of the formations to each other and to associated rocks are much confused and disguised by deformations which the rocks have suffered.

The Vermont Formation. The Vermont Formation has the following-named members at various places throughout its extent at the present surface:

a. Various basal gneisses or schists, probably altered derivatives in most cases of pre-Cambrian gneisses and other rocks, sometimes rather sharply delaminated from the parent rock, but often imperfectly transitional between gneiss and quartzite, conglomerate, or arkose.

b. Arkoses.

c. Conglomerate.

d. Granular quartz rock.

e. Massive brownish quartzites.

f. Schistose quartzites and schists.

The first-named have been described by different observers. Conglomerate is not uncommon, sometimes arkosic. White, granular quartzites are very common and pass into massive, brownish rocks, which in turn grade into schistose quartzites. The massive quartzites with conspicuous, white, granular members are of great apparent thickness and prominence in scarps along the western front of the Green Mountain plateau and by faulting are also widely distributed along the Vermont valley.

By thrusting, members of this formation may have been carried westward into the Taconic division, but this question will be discussed beyond.

Fossils in the quartzite (and the limestones) together with the field relations fix the age of these various rocks certainly in some cases and probably in the others, as Lower Cambrian.

Dolomite and the interbedded series. This formation contains:

a. At some places at least, at the base, a limestone of moderate thickness; at other places at the base a dolomitic limestone of uncertain thickness.

b. Above (a) a succession of dolomitic limestones interbedded with calcareous quartzites, rather pure, massive quartzites and schistose quartzites.

In the interbedded series the quartzitic members seem to be more abundant near the base. The more purely siliceous members range in thickness from about 2 inches to one bed at least 10 feet thick, possibly 20 feet, unless folded. The dolomitic members range from a few inches to about 3 feet in thickness.

The interbedded series is extensively developed along the Vermont valley from Bennington northward and was traced by the writer as far north as East Middlebury. It is best shown among the hills along the eastern portion of the valley and forms the visible part of most of the camel-hump arches that make up the valley floor. The outcrops of the members of this series are conspicuous features and the quartzites have undoubtedly been important factors in preservation from erosion. The series is often clearly present beneath the surface in places intermediate between the hills just mentioned. The westward extension of these rocks and their relations to other terranes will be discussed at other places.

The intimate association of this series with quartzite of the Vermont Formation is clear at many places along the Vermont valley. At Bennington the succession from quartzite of the Vermont Formation through dolomitic limestone to interbedded limestones and quartzites is particularly clear (see fig. 21). The two formations have plainly been deformed together in a large way, although the interbedded rocks appear to have suffered some independent deformation both with regard to folding and faulting.

The present distribution of the series tells nothing about its original horizontal extent.

Red Sandrock. This name has been and is now applied to a formation that shows much variation in composition and in color, and which in some localities is chiefly dolomite. The formation is practically restricted in its outcrops to the west central and northwestern parts of the State. It is prominent at the present surface around Monkton, at Snake Mountain in Weybridge and Addison, at Buck Mountain in Waltham, and thence northward through Charlotte, Shelburne, Burlington and beyond. At the south in Addison County, and also along the shore of Lake Champlain in Shelburne and Burlington, much of this rock is a quartzite and often has a dark, brick-red color. In Chittenden and Franklin counties it is described as prevailingly dolomitic. In Georgia, as early described by Walcott, it consists of a series of bluish gray, steel gray, gray massive, and reddish pink dolomitic limestones and gray, massive, arenaceous limestone, variously banded, colored, or mottled, and passes upward into the Georgia Slates.

At the Canadian line, according to Logan, it consists of white and red dolomites and sandy layers, with some strata mottled red and white and a few brick-red. Some beds were said to be very siliceous. All weather yellowish or reddish brown. The Red Sandrock series extends across the Canada line for about five miles.

The quartzitic members are all more or less calcareous and the dolomitic beds are all somewhat siliceous.

The base of this formation is not known. The formation has been described by some observers as merging with the quartzite of the Vermont Formation near Monkton.

Lower Cambrian fossils have been found at various places and within different phases of this formation.

Along the lake shore at and near Burlington, members of this formation can be seen to rest by thrust on younger (Ordovician) rocks.

Except for certain marked features of color the Red Sandrock series bears much resemblance in general sequence to the quartzite and its overlying dolomite and interbedded series that have been described.

Georgia Slates ("Georgia Group," "Georgia Slate Group"). The members of this group were first described from the town of Georgia by C. D. Walcott and were represented as conformably succeeding the Red Sandrock series. The group is typically developed in the towns of Georgia, St. Albans, Swanton and Highgate in Franklin County.

Walcott distinguished a series somewhat as follows, beginning at the base:

a. Argillacio-micaceous and arenaceous shales, with many Lower Cambrian fossils ("Georgia Shales"), 200 feet.

b. Argillaceous shales with occasional layers of hard gray limestone, ½ inch to 2 inches thick, 3,500 feet.

c. Light gray quartzite, 50 feet.

d. Gray limestone in massive layers, with intercalated bands of argillaceous shale, 1,700 feet.

e. Argillaceous shales similar to (a) conformable at base with (d) and cut off at the top by a fault, 3,500-4,500 feet.

The total thus gave the extraordinary maximum thickness of 9,950 feet. The correlation was mostly with Lower Cambrian. In 1891 Walcott described (d) of the above as appearing to be a great lenticle of limestone and the fossils as approaching the Upper Cambrian (in the absence of Olenellus).

Ulrich has "hazarded" the opinion that the upper 3,500 feet of the shale of the section described by Walcott may be of "Canadian" age (basal Ordovician). He also questions the age, in the stratum of limestone and shale to which Walcott assigned a thickness of 1,700 feet, of a limestone which gives fossils that may be of Middle Cambrian age.

The thickness assigned the series and other features may have to be revised by future study of the deformations of the region.

Roofing Slates (and associated rocks). From the northern end of the Taconic region southward along its western slopes, forming in Vermont a strip 8 to 11 miles wide north of Fairhaven and a strip from 2 to 3 miles wide south of Fairhaven to West Rupert, and extending from the north and east into eastern New

York to form a broad band in that State, is a belt of rocks known over much of its length of 70 miles or more as the "roofing slate belt." Over a distance of 40 to 50 miles the rock of this belt is extensively quarried for roofing slate.

At the northern end of the Taconic range in Sudbury, arenaceous slates and phyllites which have been described as Cambrian occur in close association with masses of heavy quartzite and again in proximity to other phyllitic rocks which have been described as of probably Ordovician age. South of Hubbardton near the western boundary of the State and across the line in New York have been described large areas of slate of probably Lower Cambrian age, as determined by fossils in associated limestones, interspersed in no regular way with slates and other rocks which have been described as of Ordovician age on the basis of graptolites found in the slates, and apparently sometimes from associated limestones and other field relations. Lower Cambrian fossils are reported widely distributed among the rocks of the slate belt and numerous localities yielding graptolites have been found.

The structural relations of the rock masses yielding these different fossils are still mooted problems.

In 1888 Walcott published a preliminary map of this region. In 1891 he correlated the Cambrian slates of this belt with those of Georgia, Vt. In 1899 T. N. Dale published a revision of Walcott's map and added many additional fossil localities to those which had been reported by Walcott.

As described by Dale the members of the slate belt are as follows:

Cambrian.

a. Olive grit (a graywacke), more or less massive, sometimes with small quartzite beds. Has associated with it, in places, a bed of quartzite 12 to 55 feet thick.

b. Roofing slates, grayish green, purple, or mixed green and purple, alternating with beds of calcareous quartzite (5 feet) and limestone breccia up to 40 feet thick.

c. Dark gray grit, or sandstone, with shaly patches.

d. Black shales or slates with thin beds of limestone breccia.

e. Quartzite usually with spots of limonite, with some variations and sometimes associated with a quartz conglomerate.

Ordovician.

a. Gray or black shales and thin-bedded limestones; possibly intermittent ("Calciferous").

b. Black or gray shales and slates, sometimes banded from bedding ("Hudson Shales").

c. Greenish or black, more or less quartzose, shales and slates, weathering white or whitish ("Hudson White Beds").

d. Gray grit (graywacke) interbedded with black shales or slates ("Hudson Grits").

e. Green or dull reddish or purplish phyllite with very thin beds of quartzite, more frequent towards the east ("Hudson Thin Quartzite").

f. Red and green roofing slate or shale ("Hudson Red and Green Slate").

Limestone is also described as occurring mostly west of the slate belt. It is called "Trenton," and is thought of as perhaps representing Trenton, Chazy and Calciferous (Beekmantown). "Berkshire Schist" (sericite, chlorite and quartz schists), containing beds of greenish quartzite up to 10 feet and over in thickness, is further described as occurring east of the slate belt, and is regarded as probably representing all the above-named terrigenous rocks called Ordovician, and as including Lorraine and Utica horizons.

Middle Cambrian.

Over most of western Vermont, so far as records obtained from present outcrops go, there is above the Lower Cambrian a great absent interval. That later Cambrian, and particularly Middle Cambrian, may have once been more fully represented is indicated by the discovery of a Middle Cambrian fauna within a rock which was designated as an "intraformational conglomerate."

This so-called intraformational conglomerate was described by G. E. Edson as formed of dark-colored, fine-grained limestone; bluish or dove-colored limestone; arenaceous shale, in which in some instances are found nodules of pure limestone and enclosed water-worn pieces of bluish-colored slate; sandstone resembling quartzite; arenaceous limestone in which the enclosed grains of sand are dark thus giving the rock a mottled appearance; and a light-colored limestone. The rocks (fragments) forming this conglomerate vary in size from small pieces to bowlders weighing many tons.

According to Edson this formation first appears at the present surface near the north line of Georgia. Here its "brecciated" condition does not appear at its best and the rock has the appearance of a massive, dark-colored, arenaceous limestone. The outcrop is described as continuing without a break to the north line of Georgia, but there disappears. It reappears northward in St. Albans. At this place the "brecciated" condition is usually well shown and the rock is in places associated with a shale. It appears intermittently northward to the St. Albans line and passes into the town of Swanton, in which town it is represented by the shale with which it is associated farther south. Northward the conglomerate appears again and passes into Highgate, to the bank of the Missisquoi River.

The State Geologist submitted specimens of the fossils found in this conglomerate to Dr. Walcott, who had in his possession some which he had collected from the same region. From a preliminary examination Walcott thought the fossils Middle Cambrian. They showed a considerable range, but *Paradoxides* was described as occurring in the matrix which would make this rock actual Middle Cambrian and an "interformational conglomerate."

As further described by Edson a *L. acuminata* was found in a shale lying close to the conglomerate. In Swanton shale is found on both sides of the conglomerate and also "interstratified" with it. On the western side shale passes under the conglomerate and dips to the east. The same fossils are described as found in the various limestones and sandstones as are found in the shale and the matrix of the conglomerate. From the descriptions it appears that the structural relations to other formations are problematical. One may hazard the opinion that the structural relations of the rocks to each other are also complicated and possibly abnormal in some cases. The possibility of the so-called conglomerate being an autoclastic needs to be considered.

Upper Cambrian.

On the New York side of Lake Champlain an Upper Cambrian sandstone is widely present and has been described as resting by depositional unconformity on pre-Cambrian rocks. Exposures occur around Port Henry, Essex, Port Kent, and Keeseville. This sandstone forms a wide fringe along the northern side of the Adirondack mass of ancient pre-Cambrian rocks. Professor Kemp has described small outliers back from the lake, west of Port Henry. On the west side of the lake faulting is common in this sandstone and in some places erosion has been heavy. This rock has long been known as the Potsdam from its type locality at Potsdam, St. Lawrence County, N. Y.

In his descriptions of the exposures around Port Henry, Ruedemann has indicated that what is regarded as the base of this formation in this region shows anomalous features in comparison with localities in Clinton County, N. Y., and on the northern side of the Adirondacks, especially in the slight development of a conglomerate and in the absence of red, hematitic arkoses, and reaches the conclusion that near Port Henry the Potsdam formation does not attain the great thickness which it has farther north and that the lower Potsdam, and perhaps the upper, were not as fully developed as in Clinton County.

East of Lake Champlain the outcrops of known Cambrian that have certainly and definitely been determined by fossils, except the "intraformational conglomerate" described above and occasional small exposures to be mentioned beyond, belong to the lower part of this system, including the rocks along the lake shore which as has already been mentioned, can be seen to rest by overthrust on greatly disturbed younger (Ordovician) rocks.

In his early studies in the town of Highgate, Walcott described a limestone conglomerate in the shale (apparently representing the rock discussed above under Middle Cambrian and later described by Edson) containing fragments of limestone varying in size from pebbles to masses 6 feet in diameter. At that time Dr. Walcott thought the fossils to have an Upper Cambrian aspect. In his later examination of specimens submitted to him by the State Geologist and in a re-examination of his own material he gave the forms a wide range, although inclined to concede a Middle Cambrian age for the matrix of the conglomerate, if *Paradoxides* occurred in it (see above, page 129).

A somewhat siliceous and magnesian limestone, associated with a thick-bedded, barren, dolomitic series that stratigraphically lies above it, is known in southeastern New York State, and in its exposures near Poughkeepsie in Dutchess County, in the Wappinger (Barnegat) limestone, was first described by W. B. Dwight and later further discussed and described by the writer. Fossils were found by both observers, consisting of brachiopods, (*Lingulepsis pinnaformis,* and others according to Dwight) and of trilobites, (*Ptychoparia,* of species found by Walcott at Saratoga). These fossils were considered to mark the rock as of "Potsdam" age. The region was mapped by the writer and the fossiliferous rock just described was found to pitch southward, in what was called the western strip of the Wappinger belt, beneath the thick-bedded, barren dolomite which was regarded as perhaps forming in part the upper portion of the Cambrian of the region and as older than other strata of "Calciferous" (Beekmantown) age lying above the Potsdam along the so-called "central strip" of the Wappinger belt as shown near Rochdale, a hamlet just northeast of Poughkeepsie.

The fossiliferous limestone in Dutchess County, assigned to the "Potsdam" by Dwight and Gordon, Walcott correlated with a rock, carrying similar fossils, which he had described as occurring at Saratoga. He has called the horizon the "Potsdam-Hoyt Limestone," and is inclined to place it in the Upper Cambrian. There is some resemblance lithologically between the rocks of the two localities thus correlated, particularly between certain gray, arenaceous beds carrying blackish streaks and patches.

Messrs. Brainerd and Seely in a paper entitled "The Calciferous Formation in the Champlain Valley," wrote with much positiveness of an Upper Cambrian (Potsdam) horizon, represented by a sandstone and a magnesian limestone directly beneath other beds which they called Beekmantown. The line between the "Potsdam" and the Beekmantown was drawn just above certain strata in which brachiopods related to *Lingula* were found.

In the writer's studies in Vermont, in the towns of Shoreham, Orwell and Benson, following in some places in the steps of Brainerd and Seely, these so-called "Potsdam" rocks were examined and their lithological similarities in some places with the Dutchess County strata, familiar to the writer, were noted. But what was more striking was the aspect of similar deformation in both cases. The characters of the Vermont rocks just mentioned will be further discussed beyond.

Mr. Wing argued for the presence of the Potsdam beneath the Calciferous in Addison County, in his descriptions of the sections near Shoreham, and gave practically the same account of the rocks as that furnished later by Brainerd and Seely. Mr. Wing also apparently, like a great many other observers of his time, regarded certain rocks that are now more generally looked upon as Lower Cambrian as belonging to the Potsdam.

In December, 1889, Walcott announced the discovery during the preceding summer of a small outcrop of Potsdam sandstone at Phillipsburg, Canada, on the east side of Lake Champlain, along the shore of Missisquoi Bay, and just north of the Vermont border. It was described as carrying characteristic fossils and as lying subjacent to limestone of the Beekmantown terrane. At the same time he mentioned the discovery during the same season in the lighter-colored members of limestone at Point Levis, Quebec, of numerous fossils of Upper Cambrian or "Potsdam" age.

In 1889 Ells described among several distinct zones of conglomerate present in the vicinity of Quebec, one at Point Levis interstratified in the fossiliferous shales of the Levis Formation and which contained a mixed fauna. Some of the pebbles held an abundance of "Potsdam" forms, while the paste of the conglomerate contained fossils characteristic of the Beekmantown formation. He further described a series consisting of red and green shales, green and gray sandstones, and beds of limestone which represents what was formerly called the "Sillery and Lauzon" of the "Quebec Group" of Logan. He considered the series to be of Upper Cambrian age.

On the Montreal Sheet, Eastern Townships map, Province of Quebec, to accompany Part J, Vol. VII, new series, Geol. Sur. of Canada, a large area, beginning about 15 miles north of the Vermont boundary and extending from Brigham Junction north-northeast to the boundary of the map, is shown as probable Upper Cambrian. The rocks are red and green shales with sandstones and grits, and belong to the upper part of the Sillery of the Quebec Group.

In western Quebec and eastern Ontario the Potsdam sandstone appears to pass without a break into the overlying Beekmantown. The lithological dissimilarity between the Potsdam of western Quebec and the supposed Upper Cambrian of the eastern

townships is very striking and is supposed to have been due to different conditions of deposition. The lower part of the Sillery is said to be undoubtedly Cambrian and to carry characteristic fossils (*Agnostus,* etc.).

Some of the rocks bordering the Sutton Mountain anticline in Quebec have also been thought to be Upper Cambrian; but the basal portion of these rocks was thought to be the equivalent of the Georgia series of Vermont and thought to lie on "Huronian."

It is now known that the conglomerate beds in the Levis Formation carry in their pebbles Lower Cambrian, Upper Cambrian (or Lower Ordovician) and Beekmantown fossils.

Ulrich has created and defined a new period and system under the name "Ozarkian," based on sections in Missouri, Arkansas and the southern Appalachians, which is made to intervene between the true "Upper Cambrian" and the basal Ordovician (Canadian). In this system he places the New York formations known as the Hoyt Limestone, the Potsdam Sandstone, the Little Falls Dolomite, and certain "passage beds" first described by Cushing from Jefferson County, N. Y., and called the "Theresa Formation."

Schuchert adopted the term Ozarkian (1909), but used it in a different sense from that of Ulrich and made it synonymous with Upper Cambrian, or "Cambric" in a restricted sense.

Schuchert has referred certain conglomerates of the "Quebec Series," whose fossils have been described by Walcott, to the "Ozarkian," as he employed the term. The formation from which the conglomerate pebbles came is not known in the St. Lawrence valley.

Schuchert would also put Brainerd and Seely's divisions A and B of their so-called Beekmantown, and apparently their so-called Potsdam also, as described for Shoreham, in the "Ozarkian," as Ulrich would also, but with a different signification for the term.

It is not fully settled whether any true Potsdam, and how much that may properly be called Upper Cambrian, can be distinguished with certainty in western Vermont.

ORDOVICIAN.

Beekmantown (Calciferous).

The Vermont report shows this formation, as traced on a lithological basis, as rather limited exposures in the western parts of Addison County and in the northwestern part of Rutland County. The thickness is described as about 300 feet. The large areas of limestone lying to the east in Addison County and northern Rutland County were called by the special name of the "Eolian Limestone."

Mr. Wing first described Calciferous fossils from this "Eolian Limestone" and is reported to have found them in the Otter Creek

Valley at New Haven, Middlebury, Salisbury, Leicester and Brandon, on the east side of the stream, and in Weybridge, western Cornwall and Shoreham, on the west side of the creek. Mr. Wing also thought the Calciferous to occur half way between Rutland and West Rutland, and also farther south.

Brainerd and Seely studied this formation particularly in the Champlain valley and with great industry examined "every important exposure on the Vermont side of Lake Champlain from Phillipsburg, Canada, to Benson, Vermont, and most of those on the New York side." From the sequence exhibited at Shoreham they estimated the entire thickness as about 1,800 feet. The formation was described as showing a variety of rock and in some beds an abundant fauna. Partly on the basis of lithology and partly by fossils the Beekmantown was separated into divisions known as A, B, C. D, and E, and described somewhat as follows (descriptions abbreviated):

1. Dark, iron-gray, magnesian limestone, more or less siliceous, often almost a sandstone, in beds usually 1 to 2 feet thick. Div. A, 310 feet.

2. Dove-colored limestone, intermingled with light gray dolomite, in massive beds. Div. B, 295 feet.

3. Gray, thin-bedded, fine-grained, calciferous sandstone; followed by thick beds of magnesian limestone; then sandstone, sometimes pure, but usually calciferous or dolomitic; magnesian limestone containing masses of chert. Div. C, total 350 feet.

4. Blue limestone in beds 1 to 2 feet thick; drab and brown magnesian limestone; sandy limestone in thin beds; blue limestone in thin beds separated from each other by thin, tough, slaty layers, often with conglomeratic appearance in the presence of small, angular pebbles. Div. D, total 375 feet.

5. Fine-grained, magnesian limestone in beds 1 to 2 feet thick, weathering drab, yellowish or brown. Div. E, 470 feet.

From Phillipsburg, Quebec, a series extends into Vermont for four or five miles in which Brainerd and Seely found beds lithologically similar to all the above-described divisions, although division E seemed "poorly represented" at the north. The Phillipsburg series was classed by Logan in his "Quebec Group," under his divisions A and B.

Beekmantown strata are described for many somewhat scattered localities along the lake shore and among the islands. The series as a whole, and the different divisions, are variously represented at the present surface in the different exposures of this formation. At Shoreham the apparent thickness is great and the formation is well represented in Orwell township and in adjacent portions of New York State.

An assemblage of remarkable fossils was early discovered at Fort Cassin. The collections which were made here by Professors H. M. Seely and George H. Perkins were described

chiefly by Whitfield and became known as the "Fort Cassin Fauna." Through the stratigraphic work of Brainerd at Ball's Bay, according to Seely, this fauna was finally assigned to the upper part of division D. Representatives of the fauna were also found at a few other places, as at Stave and Providence islands (near Grand Isle), at Valcour Island (Van Ingen and Ruedemann), and at Phillipsburg (Billings); but nowhere in the abundance and fine condition of preservation as at Fort Cassin.

The Beekmantown shows a small exposure on Grand Isle and is present at the southern end of Isle La Motte and in both places has been mapped by Professor Perkins. Brainerd and Seely, and later Cushing and Ruedemann, identified the several divisions described for Shoreham on the west side of the lake by means of similar lithologic characters.

The Vermont report shows a wide band of calciferous rock (called "Eolian") extending from Milton southward through Charlotte and Hinesburgh into Monkton. The rock is predominantly calcareous, but usually somewhat siliceous. Its precise age has proved difficult to assign. Professor Perkins classifies it tentatively with the Beekmantown, although suggesting that part of it may be Cambrian. In Colchester, Mr. Dan B. Griffin, assistant to the Survey, has found fossils (*"Pleurotomaria"* and *"Cryptozoon"*) and the State Geologist is inclined to think that this band is largely if not wholly Beekmantown.

The localities in Salisbury, Leicester and Brandon at which Wing reported Beekmantown (Calciferous) fossils were described by him as occurring west of the marble belt, and as belonging to the upper part of the Beekmantown terrane (*"Ophileta* beds"). Following the stratigraphy of that time, the quartzite lying along the eastern border of the valley being regarded as Potsdam, the limestone which lies directly west of it, "half way from Rutland to the West Rutland valley," was supposed to be Upper Calciferous (*"Ophileta* beds"), but no fossils were found.

The extent of the Beekmantown formation in Addison County, and along both sides of the lake, its northern extension into western Quebec, its representation southward in eastern New York State, and even farther south, so impressed Seely that he wrote: "and when all the geological facts are in, will it not be found that the valley quarries of limestone and masses of marble, those early known as Stockbridge and later as Rutland, are largely comprehended in the Beekmantown?"

The calciferous rock lying to the east of the marble belt in Salisbury, Leicester and Brandon, and southward through the Vermont valley, and which borders the Lower Cambrian quartzite of the plateau on the west and is associated with the quartzite of the valley, has been described as a part of the Lower Cambrian series. See above. On the map to accompany his paper on

"The Commercial Marbles of Vermont," Dale calls this somewhat regular belt of dolomitic rocks "Cambrian Dolomite." He draws a distinction only between this formation and the marble, although he includes some dolomite with the latter. In the legend he calls the whole limestone formation of the valley "Cambro-Ordovician." In the text he writes: "The marble has been shown by Wing and others to include beds of Chazy age and probably some of Trenton age above them and possibly some Beekmantown below them. There is, however, a question whether any or how much of the dolomite is of Beekmantown age. As this formation along Lake Champlain is largely dolomitic it would naturally be sought among the dolomite beds of the Vermont valley."

In the present state of knowledge the assignment of any portions of the limestone of the Vermont valley to the Beekmantown is conjectural and provisional.

Dale has described a number of localities in the slate belt which exhibit certain dark-gray, calcareous or very quartzose, finely-bedded shales or black shales with thin limestone beds. These rocks are described as inconspicuous and easily overlooked. They are of inconsiderable thickness, and are further characterized by extremely fine bedding and a graptolite fauna. These features serve to distinguish them from adjacent rocks. While some of the fossils have a range outside the Calciferous (Beekmantown), several of them are regarded as probably of Calciferous age. It is uncertain whether the horizon is everywhere present or only intermittent.

In eastern Quebec is so-called Calciferous (Levis Formation) which is very different lithologically from the Beekmantown described from western Quebec, Ontario, Vermont, and eastern New York. It consists of black, gray and green shales, and beds of dolomites, sandstones and conglomerates, the latter carrying Cambrian fossils (Walcott). As explained on the map to accompany Part J, Vol. VII, new series, Montreal Sheet, Eastern Townships, the Levis is supposed to be the age equivalent of the western Quebec Beekmantown and the differences in lithology as due to different conditions of deposition. The Levis shales carry a very different fauna from the western Beekmantown. The fossils are graptolites which were correlated by Lapworth with Arenig (basal Ordovician) of England. This correlation is said to ally the Levis fauna with a different faunal realm from that of the Beekmantown of the lake region, the latter being the eastern extension of a "Pacific realm" fauna which was prevented from intermingling with the eastern European fauna represented by the Levis by a land barrier which separated the "Levis trough" on the east from a more western "Chazy trough" on the other side of the Green Mountain axis.

As explained in the discussion of the Upper Cambrian, Schuchert, and Ulrich by implication, place the lower portion of

Brainerd and Seely's Beekmantown in the "Ozarkian," which Schuchert makes Upper Cambrian and which Ulrich regards as a separate system, belonging to the basal Ordovician.

It has been suggested that the upper part of Brainerd and Seely's Beekmantown is probably more closely allied with the Chazy.

Chazy.

In the Vermont report the Chazy was grouped with Birdseye (Lowville) and Black River, which together were shown forming a strip about five miles wide narrowing north and south, along the shore of Lake Champlain in Addison County. Other strips were shown on Grand Isle and Isle La Motte.

First Wing and later Brainerd and Seely extended our knowledge of the occurrence and distribution of the Chazy rocks.

Wing found the Chazy well represented by fossils at West Rutland in the "Eolian Limestone," and reported other fossils from Leicester, East Cornwall and Middlebury.

On a map to accompany a paper entitled "Preliminary Report of the Geology of Addison County," Seely later showed no Chazy in Addison County east of the eastern boundaries of the towns of Addison, Bridport and Shoreham. On page 308 of the paper he wrote: "The deposits at the lime quarries near Leicester Junction have been regarded as massive Chazy and yet the structure approaches the Beekmantown. As Beekmantown it may remain until new light is thrown upon the obscure problem."

Wing described a "striped stratum" which was regarded as a marked feature of the Chazy, "by which the rock may be recognized without its fossils." This was found in Middlebury, in northern Salisbury, in the western part of Brandon, and in western Pittsford. This stratum "doubtless reaches the marble quarries of West Rutland and continues southward through Tinmouth and the whole State."

Chazy fossils were also reported by Wing from West Cornwall, North Cornwall, Orwell, Weybridge Upper Falls and near Bristol village.

In 1891 Brainerd described sections at Valcour Island, Crown Point and Chazy, N. Y. and also at Isle La Motte, Cornwall, Orwell and Highgate, Vt., and at St. Armand, Quebec. At Valcour Island 890 feet of Chazy were measured and separated into divisions designated as A, B and C, corresponding to Lower, Middle and Upper Chazy.

The distinction among the different divisions of the Chazy was made on the basis of fossils and lithology. The lower and upper boundaries of the formation were ultimately established and when all the lower members are present it has now for its recognized base a ferruginous sandstone which is prominently developed at Isle La Motte and is known as the "Isle La Motte sandstone." It carries *Lingula limitaris,* Seely, as a character-

istic fossil. This sandstone rests, according to Seely, upon different members of division E of the Beekmantown, but usually upon the upper ferruginous limestone of that division. The upper strata of the Chazy, though varying somewhat, bear most often a tough, magnesian limestone, destitute of fossils, and weathering with an iron stain, while just above is a layer of flinty sandstone.

At Valcour Island the Chazy is described as follows (abbreviated):

1. Gray or drab-colored sandstone, usually with thin layers of slate and with occasional thin layers of limestone at the base; passing into massive beds made up of thin, alternating layers of tough slate and of nodular limestone; dark, bluish-gray, impure limestone in beds of variable thickness; gray, tolerably pure limestone in beds 8 to 20 inches thick, separated by earthy seams. Lower Chazy, Group A, 338 feet.

2. Impure, nodular limestone; gray, massive, pure limestone; bluish-black, thick-bedded limestone, usually weathering so as to show pure nodular masses in a somewhat lighter matrix; dark, compact, fine-grained limestone, with obscure bedding; bluish-black limestone. Middle Chazy, Group B, 350 feet.

3. Dove-colored, compact limestone in massive beds; dark, impure limestone in thin beds; tough, arenaceous, magnesian limestone passing into fine-grained sandstone. Upper Chazy, Group C, 202 feet.

Like the Beekmantown, the Chazy throughout its distribution at the present surface shows some variations in characters and thickness of members and at some places only partial representation of the formation.

In addition to the localities given above, exposures of Chazy occur near Balls, MacNeils and Merriams bays, and from Basin Harbor to Button Bay, along the east shore of the lake; at the northern end of Providence Island; on Sawyer's Island; and on Grand Isle, where it is represented somewhat extensively, both geographically and as a terrane.

After the discovery of characteristic Chazy fossils (*Maclureas*) at the surface in the central and western parts of the West Rutland valley fine, although somewhat distorted, specimens were found on polished slabs from the bottom of the deep "Ripley quarry."

South of West Rutland, in the town of Ira, at Day's quarry, which was worked for a time, Walcott found sections of large gastropods, probably *Maclureas,* in a bluish marble.

South of West Rutland in the Vermont valley recognizable Chazy fossils, so far as the writer can determine, had not been found up to the season of 1920. See beyond. Dr. Walcott discovered fossils in the limestones south of Bennington, which were assigned to the Chazy-Trenton, but no sharper distinction was drawn.

Lowville (Birdseye).

In the generalized time-scale for eastern North America the Lowville succeeds the Chazy.

An elevation at the close of Beekmantown time, accompanied by folding, in eastern North America, has been described as probable. This elevation is thought to have raised much of the middle Appalachian region and all of New York State except the northeastern portion above water. In the Champlain region it is held existed a trough at this time in which was being deposited the Chazy. While the Chazy was being deposited in the Champlain region and in another small (Ottawa) basin the lower Stones River was depositing in Kentucky and Tennessee.

After the deposition of the Chazy in the Champlain region it is thought an emergence there occurred, forming land, which was not submerged again until the Black River brought the Mississippian sea into the region. The Lowville, which is regarded as the time equivalent of the Upper Stones River of the south, forms the basal member of the Trenton series (Mohawkian) in New York and ushered in the Black River invasion.

As mentioned in the discussion of the Chazy the Lowville was theoretically included with Chazy and Black River in the Vermont report.

The Lowville was at first described as very scantily represented in Vermont. *Phytopsis tubulosum,* Hall (a fossil which has the appearance of a bird's eye and which gave the early name to the formation), has been seen only in the northwest corner of Benson in a bed about 6 feet thick. Elsewhere this horizon is described as having only a few feet of pure, fine-grained, brittle limestone with fine lines of calcspar, lighter in color than the known Black River strata just above, and without fossils.

Brainerd and Seely maintain that more than one horizon in the Beekmantown and in the Chazy are lithologically similar to the Birdseye, and have been wrongly assigned to that formation. Assuming the rocks and fossils which had some appearance of the Birdseye to belong to that formation they sought localities where the Chazy approaches the Black River, thus hoping to find the Birdseye between. But in every locality so sought they found the Black River resting upon the Chazy, with no room for the Birdseye. Instead they found the so-called Birdseye in places to be underlain and overlain by members of their Calciferous. They found fossils which have been figured as sections of *Phytopsis tubulosum* to be "spongoid" forms, known as *Strephochaetus,* characterizing their middle Chazy. They could find no proof of the Birdseye in Vermont, except the small exposure in Benson.

Black River.

In their description of the Beekmantown of Vermont, Brainerd and Seely frequently refer to the Black River as immediately overlying their Chazy. Northeast of Shoreham village they mention Black River, carrying characteristic fossils, lying in a trough of the Chazy. Half a mile south of this exposure the trough widens and the Trenton appears flanked by the Black River and the Chazy in succession. Again in Orwell, south of Shoreham, Black River is described as resting against the Chazy, the latter lying on the former at one place by overturn. Black River is described at Larrabee's Point, Thompson's Point and MacNeils Bay.

In his paper dealing with the Chazy of the Champlain valley, Brainerd describes and shows graphically in sections the Black River at Valcour Island, Isle La Motte and Highgate Springs, resting upon or in close association with Chazy.

Professor Perkins has mapped five separate exposures of the Black River on Grand Isle, and one on Isle La Motte, and refers to it as occurring at Button Bay Island and at Benson.

The Black River strata are described as fine-grained limestone, bluish at the base and jet black in upper layers. The formation as a whole is nearly destitute of fossils, although some thin layers are full of them.

Except in the vicinity of Lake Champlain the Black River is not positively known in Vermont.

In the Champlain region the Black River has been thought to lie disconformably upon the Chazy, the latter having been elevated and probably somewhat eroded before the Black River invasion.

Trenton.

This formation as identified by fossils differs in lithology and degree of metamorphism at different places. Some terrigenous rocks by reason of association with Trenton limestone or other relations have been described as probably of Trenton age.

The Vermont report shows the Trenton at Highgate, on Isle La Motte, and on Grand Isle in Lake Champlain; in Charlotte on the lake shore; and in the western portions of Addison and Rutland counties.

Mr. Wing later added details of the Trenton in Addison County and also found Trenton localities in the "Eolian Limestone." West of or within the slate belt of the Vermont report he identified the Trenton at localities only a few miles apart in all the towns north of Castleton, including Hubbardton, Sudbury, Whiting, Shoreham, Cornwall and Weybridge; and on the east of the slate belt in Leicester, eastern Cornwall and Middlebury. The presence of the Trenton at Benson, south of Orwell, left

little doubt that this formation exists "in long bands stretching down on the west of the two belts of slate from Weybridge southward."

From the relations of the "central slate belt" to the marbles in Rutland County and farther south, Wing believed the Trenton abundantly represented in the marble belt. Fossils (*Trinucleus concentricus*) were described as found in limestones "interbedded" in the slates 10 miles southeast of Sudbury, at Hubbardton, and a mile or two north of the slate quarries at West Castleton.

In the summer of 1887 Walcott found fossils indicative of a Trenton fauna at Pownal, Vt., a mile north of the Massachusetts line, and also on the eastern side of Mt. Anthony about 3 miles south of Bennington Centre.

In the papers by Brainerd and Seely on the Calciferous and Chazy of the Champlain valley, frequent mention is made of Trenton rocks. They are described as forming a wide strip east of Shoreham, running through Cornwall and Whiting on the west of the "central slate belt"; also at Shoreham; at Orwell; at Larrabee's Point; to the east of Balls Bay; at Cedar Branch, north of MacNeils Bay; on Grand Isle, both inland and along shore; at Crane Point, opposite Port Henry, N. Y.; and at Isle La Motte.

Professor Perkins has shown wide exposures of this formation on Grand Isle and has also mapped its outcrops on Isle La Motte.

Small exposures are mentioned as occurring at Highgate and St. Albans, but they are in no cases extensive. The formation is described as not occurring along the lake shore north of Charlotte.

Dale thinks that some of the limestones of the marble belt are of Trenton age. On his map of the slate belt of eastern New York and western Vermont, Ordovician limestone is shown as an interrupted band along part of the western border. In Benson this limestone, with a few small patches of slaty or gritty rocks, is represented as a band 2 miles wide along the shore of the lake. Just east lies the so-called "Benson Black Slate" over an area about 2 miles wide and 5 miles long and this is bounded on the east by an irregular strip of the limestone. These two areas of limestone are shown as separated at the south from another area of the limestone about 2½ miles wide south of West Haven. The latter area narrows southward, and with only one interruption, extends to West Granville, N. Y. Fourteen miles south of West Granville a narrow band runs from North Argyle to Argyle in New York. In the text these areas are referred to as the Trenton limestone. Outcrops are specially mentioned as occurring in Hartford and at Carver's Falls in Poultney River. An area is shown northwest of Hubbardton, surrounded by the slate, phyllite and grit formation. At Carver's Falls and at several other points near the Cambrian boundary, with which the lime-

stone is shown in contact over long distances, according to the map, the limestone yields Trenton fossils. In several places this limestone "may represent the entire Lower Silurian series and should then be regarded as Trenton, Chazy and Calciferous." The Trenton limestone is mentioned as occurring sporadically within the Ordovician areas of the slate belt.

In general as thus far described the Trenton formation is calcareous. Several observers have regarded limestone of this age as interbedded with members of the slate formation. Dale says that the limestone was probably in some places deposited contemporaneously with the "Hudson" grits and shales. In his table and descriptions of formations, those designated as "Hudson grits, Hudson red and green slates, Hudson thin quartzite," are put in the Ordovician and in part referred to or described as probably representing the Trenton limestone, described above as occurring west of the slate belt. Dale describes what appeared to him as indications of transition between Hudson grit and the "Berkshire Schist" of the Taconic range, and from the areal relations infers that the latter is equivalent to the entire Ordovician among the slates and grits and in addition to representing the Calciferous, Chazy and Trenton includes also probably the Lorraine and Utica.

Foerste describes Trenton fossils as occurring in thin blue limestone which forms intercalated bands in the base of the slate formation. He gives two localities near Danby Four Corners, 12 miles south of Rutland, and another on the ridge west of Otter Creek a little northwest of South Wallingford. He mentions branching bryozoa, crinoid beads, and sections of *Strophomena* and *Streptelasma*.

Normanskill.

Graptolite shales "interbedded or associated" with "Hudson" grits in the slate belt are assigned to the Normanskill Zone (Trenton) by Dale.

Utica.

The so-called "Utica" has a wide distribution in the region of the lake. The Vermont report, which separates this formation from the "Hudson River," shows the Utica as forming Alburgh peninsula, North Hero and much of Grand Isle, and on the mainland of Vermont further indicates a strip extending from the shore of Missisquoi Bay southward through Highgate and Swanton to St. Albans Bay; again at the mouth of the Winooski River and from Charlotte on the east of the Trenton limestone south to Shoreham. It is described as pinching out in Orwell near "Chittenden's Mills." A narrow strip is shown skirting the lake on the west of the Trenton in Addison County, and a small patch on the lake west of Bridport.

According to Professor Perkins what was mapped by the Vermont Survey as "Hudson River" is also Utica. According

to Perkins: "Here and there the Utica appears on the Vermont shore of Lake Champlain and in small patches away from the lake." Juniper Island, the Four Brothers and Rock Dunder in the lake are also formed of Utica slate.

Mr. Wing's investigations apparently dealt chiefly with the limestone formation ("Eolian"), and only indirectly with the slate. The slate of the great "central slate belt" of the Vermont report he called "Hudson River" and showed it in sections and discussed it as conformably overlying the Trenton formation. At West Rutland "the Chazy adjoins the slate belt." The limestones containing Trenton fossils "over the interior" of the slate belt had the appearance of being "brought up from beneath by anticlinals."

Brainerd and Seely maintained that all the rocks of the Lower Silurian appear on the Vermont side of Lake Champlain, sometimes showing in their natural order in great monoclinals with Utica slate at the top, lying on the Trenton limestone. They made the slate of the "central slate belt" which Wing called "Hudson River" in the Shoreham section, of Utica age, thus correlating it with the slate formation lying west of the "great fault," or the slate of the Lake Champlain region proper. These observers show the Utica in faulted contact with the Chazy and Trenton at Isle La Motte. Professor Perkins shows the Utica widely distributed on Grand Isle, forming the larger part of the island; also three patches along the east shore of Isle La Motte.

Within the roofing slate belt the Utica is not distinguished. East of the slate belt the Berkshire Schist is made probably to include this horizon.

On Grand Isle Professor Perkins has described characteristic Trenton fossils and so-called "Utica" types occurring on the same slab.

Later Ordovician ("Lorraine," "Hudson River").

The presence of rocks of Ordovician age younger than so-called "Utica" in western Vermont cannot be affirmed from the rocks themselves. Perkins maintains that in the Lake Champlain region all the slate formation is of Utica age (or older perhaps).

In the Taconic range the Berkshire Schist is made provisionally to include Lorraine, and many of the terrigenous rocks of the roofing slate belt are not specifically assigned beyond indicating that some of them are probably equivalent to the Trenton (and the Calciferous and Chazy). They are usually referred to by the non-committal term "Hudson," which term in its present usage, includes Trenton and older and younger terranes.

GENERAL STRUCTURAL CONSIDERATIONS.

Preliminary statement. Throughout their length and breadth in western Vermont, from the Canadian boundary to the Massachusetts line, and in their geographical extensions into Quebec at the north and into Massachusetts and New York at the south and west, the formations just discussed present a wonderfully fascinating field with respect to the secondary deformations which they have suffered. For a bold sweep of the imagination there is no aspect of Vermont geology so inviting as that of the widespread dislocations which have followed the action of compressive stresses in the earth's crust. By these forces the rocks have been piled on each other and shoved from east to west.

In the Taconic region the deformational history is very complicated and difficult to read. Many views of the structure have been given and there probably will always be divergence of opinion.

The present erosional aspects of the region in many particulars seem clearly to be due to structure produced by ancient processes of deformation and as one studies the topography and geology together it becomes apparent that the physiography of today had its genesis in crustal disturbances of a more or less remote past.

Brief summary of various studies that have been made in the deformation of the earth's crust in various parts of the world, and of certain theoretical aspects of the subject. In their work of mapping the areal and structural relations of formations in various parts of Europe and of this country during the past forty or more years, geologists have in some cases readily come to recognize and sometimes have been forced to reckon with the existence of great displacements of the crust in order to account for the field relations which certain regions show. Especially noteworthy is that class of deformations comprising overturned folds, shearing, reverse faults and thrusts.

All these secondary structural features often share with each other the displacement changes of a given region and sometimes apparently have a common general relation to a definite regional deformation. Uncertainties will naturally arise concerning the extent to which the various secondary deformations due to compression, in a given region, are related to the same general episode; or, if there is reason to think that pressure acted intermittently, as to whether it acted in the same direction at various times. Evidence has been offered to show that in certain regions thrust movements have been widely separated in time and have acted in practically diametrically opposite directions.

It is usually not easy to fix the precise, or even the proximate, date for the chief displacement features of a region, or to apportion the various deformations therein among different epochs in those cases in which a region is known or suspected to have been

affected by crustal movements more than once and at more or less widely separated times. The degree of probability rests upon different conditions in different regions. In certain regions where older formations now rest by thrust on younger masses, these relations by themselves may serve to indicate only a general limit of antiquity and other conditions may or may not give an idea of the precise date at which the actual deformation occurred.

Sometimes the evidence points to the formation of a major thrust whose plane was subsequently folded and suffered offsets and other later disturbances. The latter may in certain regions be reduced to a type characteristic of later orogenic movements or other displacements and serve to show at least separate episides of disturbance, while they leave undecided the question of how much earlier the major thrust occurred than did those movements which modified it in various ways.

In certain cases perhaps the existence of a stratum competent to transmit a great lateral thrust may serve to indicate the limit of antiquity of the movement, while the relations at the same time afford no means of telling at what time subsequent to the formation of the competent stratum it was called upon to exercise its influence. The problem might perhaps be further complicated in some cases by the possible former existence of a competent stratum which had been partially or wholly eroded and which by reason of its original relation to the load which it carried could have initiated a thrust which was participated in by a lower stratum, also competent under proper conditions, which obtained relief by the fracture initiated by the more superficial part of the crust, the fracture of the latter changing the relations between the deeper stratum and its load, which had prevented fracture until the relief of the initial fracture was felt by it.

In some cases a thrust movement may not have occurred until erosion had so changed the relations of a stiff stratum with respect to its load that it fractured, in which case the thrust would be thought of as occasioned by reason of erosion preceding or assisting compression. In a case in which erosion preceding any compression seemingly made possible a thrust movement and in which the erosion was apparently carried to a stage of peneplanation prior to the thrust, the date of the peneplain, if ascertainable, might serve to fix the probable date of thrust.

In some regions the fact of different dates of compression might be perceived by reason of the difference in degree of displacement produced as, for example, where it would be possible to associate one class of fractures with the folding of an earlier thrust of relatively large displacement.

While it is possible to imagine the formation first of a major thrust whose plane was subsequently disturbed by folding and thrusts, there are regions in which the conditions seem clearly

to indicate that minor thrusting or reverse faulting along many separate planes and apparently involving previous folding, occurred first, piling the strata on each other, sometimes to enormous thickness, and that a later thrust passed beneath the whole and cut off the whole series of earlier minor thrusts whose planes came to lie at oblique angles with the major thrust plane. More than one series of minor thrusts, or reverse faults, and an associated major thrust may exist in the same region, which suggest different episodes, or periods of compression, for that region. Moreover, in addition to these minor and major thrusts there may be one or more later and still more powerful or "maximum" thrusts, so formed that the later of these override the earlier, while all may overlap the previous minor and major thrusts of the region, at one or more places. A very complicated condition is thereby produced. The maximum thrusts carry the older rocks over the younger, but with various degrees of overlapping, and the overthrusting may go so far as to carry the disturbed portion of the crust over on undisturbed strata. While a common direction of movement and a sequential nature in these displacements and therefore their relative dates might be apparent, the question of their geological dates might still remain open.

A condition that might be inferred to be due to folding antecedent to thrusting is frequent in such regions as just described, but it is explained, sometimes at least, as occasioned by friction along the unyielding plane over which the upper material moved, so that there was a tendency for the upper part to curve under and produce inversion of beds.

The outcrops of the maximum thrust planes under erosion resemble boundary lines between unconformable formations because of greater or less discordance between the strata above and below the plane of fracture.

In regions of long-continued and profound erosion and involving at the present surface very old rocks the problem of the dates of various disturbances may shift to one of sheer uncertainty, especially when a region is known or believed to have been involved in two or more mountain building deformations and one or more of these disturbances are also known to have been a long time subsequent to the dates of formation of the rocks which now lie in displaced relations to each other. It is conceivable that a relatively recent orogenic movement might have dislocated and deformed a region involving rocks of much greater antiquity than the date of the movement itself and give results not to be readily distinguished from those which would have followed a compression of those rocks shortly after their formation.

Displacements have been described in the Canadian Rockies in which an original width of 50 miles has been shortened to half that distance by a succession of thrusts along a number of

parallel, longitudinal fractures which have produced a series of huge oblong blocks resting on one another from west to east, and apparently produced without much preliminary bending. Overturned folds were observed along the courses of some of the faults, but were described as usually small and of minor structural importance. Violent folding in the prolongation of a fault line and undulations of major fault planes indicating disturbance subsequent to the main faulting were observed. In the belt of fracture there were recognized seven principal faults of varying throws. *There was observed a very striking apparent conformity between beds widely different in age east of the axis of the region.*

It will appear, either in regions in which strata belonging to epochs approximating in age relations the date of later deformations have never been deposited, or in those in which such strata though deposited have been eroded, as though only those rocks which are now visible were involved; but in one case it will be necessary to recognize that a former load may have controlled or modified the action of the deforming forces. It may be that the only light one may be able to get upon such a possibility will come from considering the whole general region, of which the province under consideration is apparently a genetic part. Late Paleozoic rocks, for example, may be much more sparsely represented today in New England than in the past. The conditions in neighboring New York and the fact that we are probably dealing with an upraised peneplain of a great upthrust segment of the crust should perhaps be remembered in our studies in western New England.

The probability of difficulty in working out the dates of deformations in a region as the result of the fact that nature works, at least to some extent, with the same rock masses at separate epochs and under various conditions is apparent. Such conditions, in efforts to discriminate among the effects of possible different crustal movements, will lead to differences of interpretation almost surely where present relations are greatly involved.

In passing it seems worthy of note that any principle which assumes that the minor, secondary structural features of a region may be taken as replicas of the larger deformations must be used with caution.

The problem of the structure of a region often involves as primary conditions the nature, sequence and thickness of sedimentary formations and the complex nature of the substratum on which these are deposited, such as rigidity, condition of previous strain, irregularity of surface and admixture of crystalline masses. It must further reckon with antecedent deformation of any kind and frequently upon consequent strains in those cases in which the structural features are of different dates. It must take account of the possibility of variations in the strength of the

compressive forces at different times, or in different parts of a region during the same episode; of metamorphism and resulting crystallization or re-crystallization of rocks; of erosion at different periods; and of periods of tension stresses and normal faulting.

DESCRIPTION AND DISCUSSION OF FIELD STUDIES BY THE WRITER IN WESTERN VERMONT.

General plan of discussion. For convenience, general reference to field studies in this paper will be given by counties and by towns which are shown on the accompanying map, plate XXII. Observations and citations are based on the topographic, quadrangle sheets of the United States Geological Survey. Close reference to localities mentioned will require the use of these maps. Some assistance may also be had from the map showing physiographic divisions, and from certain landmarks such as large towns or cities, township boundaries and rivers. For the townships of Brandon, Sudbury and Orwell a special map is offered, Plate XXII.

ADDISON COUNTY.

Orwell Township.

(Ticonderoga topographic sheet.)

Topography. The township has a somewhat diversified topography. A spur of the foothills of the Taconic range enters it from the town of Benson at the south. Over this spur the contours of 600 and 700 feet run for long distances. The highest point is 1,000 feet. There are several scarps within the spur.

This high land extends nearly to the lake in southwestern Orwell, but the surface of the northwestern part of the town is a gently-rolling upland with contours at or below the 400 level. The surface of East Creek over much of its length is practically that of the lake. Along the creek and the lake shore are large tracts of Champlain clays, which effectually conceal the underlying rock.

East of the spur described is a valley through which courses the Lemon Fair River and which separates the spur from the Sudbury hills. This valley has a minor ridge running in a general north-south direction through it.

Mount Independence. The flattish position of the strata forming this hill is noticeable. They dip about 10° northerly. Forming the basal members at the southern end are thick-bedded, whitish, quartzitic sandstones which Brainerd and Seely called "Potsdam" and assigned a thickness of 170 feet. Then come dark-gray, siliceous and magnesian rocks, in some cases almost quartzites, and then interbedded dolomites and limestones. The rocks of the hill above the so-called "Potsdam" were called Beek-

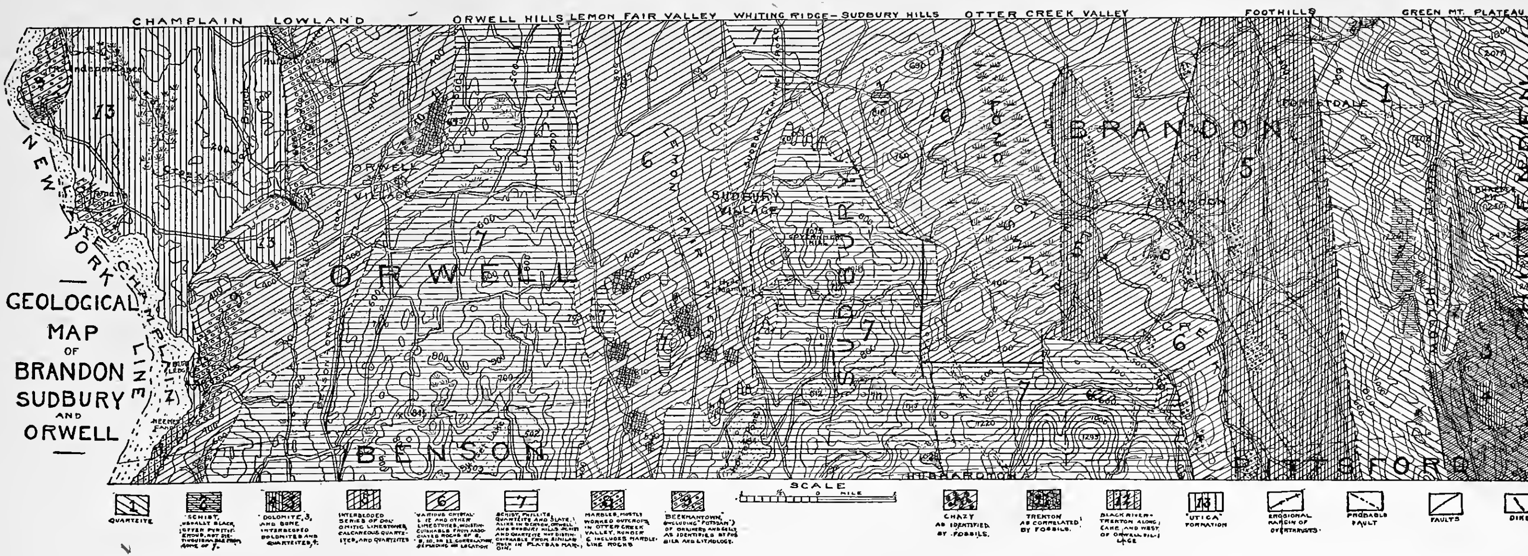

CHAMPLAIN LOWLAND
ORWELL HILLS
LEMON FAIR VALLEY
WHITING RIDGE – SUDBURY HILLS
OTTER CREEK VALLEY
FOOTHILLS
GREEN MT. PLATEAU
GEOLOGICAL MAP OF BRANDON SUDBURY AND ORWELL
NEW YORK
CHAMPLAIN LINE
ORWELL
ORWELL VILLAGE
SUDBURY
SUDBURY VILLAGE
BRANDON
BENSON
PITTSFORD
HUBBARDTON
SCALE
MILE
QUARTZITE
"SCHIST, USUALLY BLACK, OFTEN PYRITIFEROUS, NOT DISTINGUISHABLE FROM SOME OF 7.
"DOLOMITE, 3, AND SOME INTERBEDDED DOLOMITES AND QUARTZITES, 4.
INTERBEDDED SERIES OF DOLOMITIC LIMESTONES, CALCAREOUS QUARTZITES, AND QUARTZITES
MARBLES, MOSTLY WORKED OUTCROPS IN OTTER CREEK VALLEY. NUMBER 6 INCLUDES MARBLE-LIKE ROCKS
BEEKMANTOWN, (INCLUDING "POTSDAM") OF ORDINERS AND SELLY AS IDENTIFIED BY FOSSILS AND LITHOLOGY.
CHAZY AS IDENTIFIED BY FOSSILS.
TRENTON AS CORRELATED BY FOSSILS.
BLACK RIVER-TRENTON ALONG LAKE AND WEST OF ORWELL VILLAGE
"UTICA" FORMATION
EROSIONAL MARGIN OF OVERTHRUSTS.
PROBABLE FAULT
FAULTS
DIKE.

PLATE XXII.

mantown (Calciferous) by Brainerd and Seely and put in their divisions A and B. The writer did not find along the lake shore or at any other part of the base of this hill any contact with other rocks than those which make up the hill. It seemed to be surrounded on the landward portion by the Champlain clays.

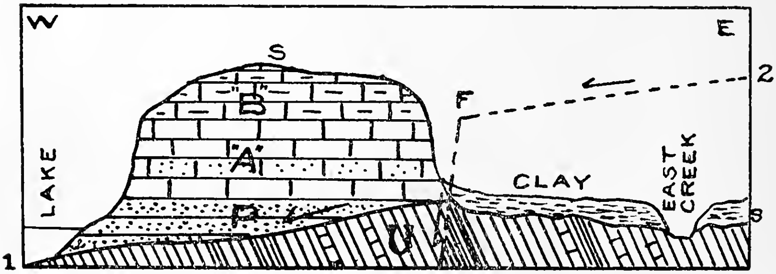


FIGURE 9. Section to show interpretation of the relations at Mt. Independence. U, "Utica" slate; P, "Potsdam"; "A" and "B," lower "Beekmantown." The lower Ordovician has been thrust on the "Utica" slate formation. A possible normal fault, F, is shown which displaced the whole series at the west, including the thrust plane. 1-2, thrust plane. S-S, erosion surface of the hard rock formations.

Chipman's Point. One and a half miles south-southeast of Mt. Independence thick beds of dark-gray, magnesian limestone emerge from the lake north of Chipman's Landing, with general northerly dip and strike of N. 58° E. One-half mile southeast of the landing these beds which seem to have suffered no break within them, disappear into the lake with general southerly dip, thus appearing to form a gentle arch with general direction of its axis east and west. So far as observed along shore these beds are similar to those lying above the "Potsdam" in Mt. Independence. At many places the rocks dip abruptly into the lake. No so-called "Potsdam" was observed. Eastward these rocks pass beneath the clays. No contacts with other rocks were found. The strata indicated only gentle deformation within them.

South of Chipman's Point. South of Chipman's Point are three promontories known by campers along the shore as "The Phoebes." These are composed of black, limy slates and shales with bands of interbedded black limestone. All are much disturbed and show not only a highly-inclined easterly dip as a rule, but internal crushing as well. The shaly members of the southern promontory gave *Graptolithus pristis,* and bowlders of the interbedded limestone at the base of the cliff yielded *Plectambonites sericeus, Dalmanella testudinaria,* and *Trinucleus.*

One hundred and fifty rods south of this promontory a brook enters the lake. Slate outcrops in the bed a few rods from the shore and is succeeded up the brook by a magnesian limestone, dipping easterly and resembling part of the lower Beekmantown of the exposures at the north. In the field northeast of this

brook are dark, magnesian limestones. In lithology and presence of chert, some of this rock resembles division A of Brainerd and Seely's Beekmantown. This is succeeded eastward by other magnesian limestone of general gray color and probably part of the Beekmantown.

South of this brook is a hill known as "Blue Ledge" by the campers. The ledge shows an almost perpendicular scarp from 150 to 200 feet above the surface of the lake. The west face of the scarp to a height of 100 plus feet is composed of slate like that of "The Phoebes" at the north. The shaly layers yielded *Graptolithus pristis.* The summit of the scarp and the eastern slope of the hill is a magnesian limestone like that in the brook bed just north and is probably Beekmantown. The topography shows that "Blue Ledge" is bounded on the north and south by east-west faults of the normal type. The limestone capping the hill dips easterly. See figure 10.

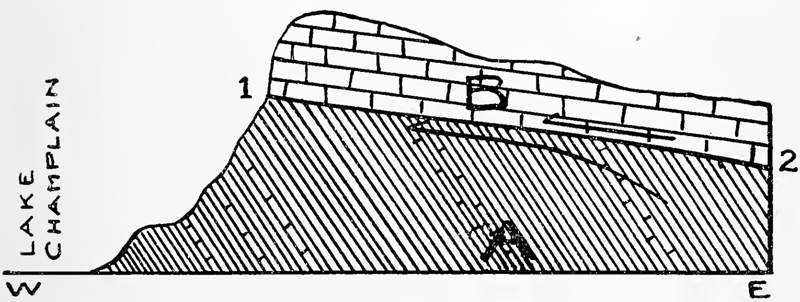


FIGURE 10. Section to show relations at "Blue Ledge," on the Orwell shore of Lake Champlain. A, "Utica" slate formation; B, massive dolomite, probably of "Beekmantown" age; 1-2, thrust plane. Curved arrow indicates folding of "Utica" strata; straight arrow indicates bodily thrust of massive "Beekmantown" on slate formation.

South of "Blue Ledge" is an abandoned farm. Just north of the old barn is an exposure of the "Utica" and not more than 10 yards to the east of the slate is a low scarp in the dolomite, but the contact is concealed. These relations are shown in plate XXIV.

The relations at "Blue Ledge" and at the old farm thus give clear and unmistakable evidence that the slate formation is overlain by the dolomite which is all regarded as forming some part of the Beekmantown of the region, on the basis of the lithology of the rock. The indication is that "The Phoebes" owe their present topographic prominence to a protective covering of the Beekmantown which has been removed at a relatively recent epoch. For the Beekmantown to have its present position on the younger formation an overthrust is assumed.

Questions then arise with reference to the former extension of the Beekmantown in the neighborhood. Is it present

beneath the clays between Chipman's Point and Mt. Independence? If not, was it once present there lying on the slate formation and did it also once cover the slates to the east of the lake shore over the areas now largely concealed by clays, but in which along the various stream incisions the slates can be seen to form the surface rock? East of these clays and west of Orwell village, as will presently be described, the Beekmantown occurs again and in apparent overthrust relation to the slates. It therefore appears probable that these questions just asked as to a probable, former, widespread covering of the slates by Beekmantown may be answered in the affirmative.

The conditions at Mt. Independence, at Chipman's Point and at other places indicate gentle flexures in the dolomite formation; while those at "Blue Ledge" and west of Orwell village show that the formation has been fractured. It appears probable that certain structural features permitted the removal of Beekmantown beds over the areas intervening among its present surface outcrops and that Mt. Independence, and perhaps also the dolomite at Chipman's Point, are thrust-erosion inliers in the slate formation. On the whole it appears probable that the present exposures of the dolomite are the downthrow portions of the formation as deformed by normal faulting and that many of the flexures which the formation shows are products of the same deformation.

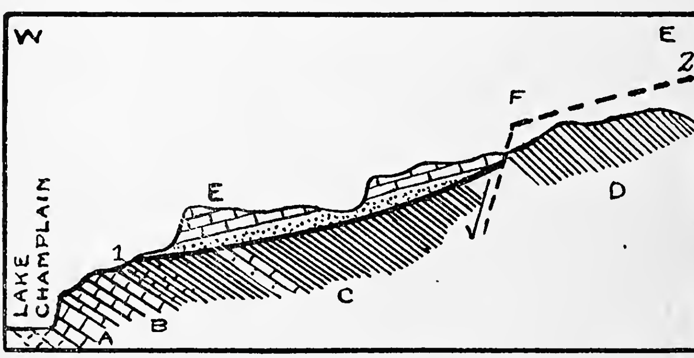
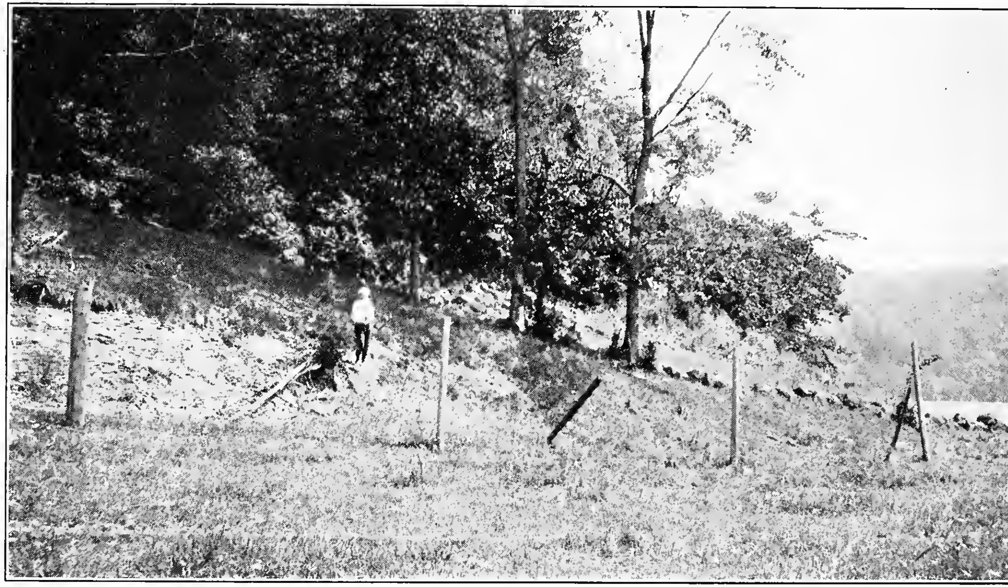


FIGURE 11. Generalized section to show interpretation of relations along the lake shore in Orwell just north of the Benson line. A, Black River; B, Trenton; C, Trenton-"Utica"; D, friable shales probably conformable with C; E, "Potsdam" and "Beekmantown" now lying by thrust on A, B, C, and formerly also on D. A normal fault has dropped the rocks at the left, including the thrust plane. On the upthrow side E has been eroded and also part of D. 1-2, thrust plane.

Southeast of the old farm mentioned above is a very bold precipitous scarp in the dolomite. In the face of this cliff the rocks appear very massive and exhibit little appearance of bedding. The scarp loses prominence southward owing to the drift piled against it; but it was followed through the woods

PLATE XXIV.



Contact of massive "Beekmantown" on the "Utica" slate near the shore of Lake Champlain in Orwell, one-half mile north of the Benson line. The boy stands on the slate; the "Beekmantown" shows as a scarp midway up between the trees.

above the camp of Oscar Neemes to an apparent fault that will presently be described.

Along the shore one-half mile south of "Blue Ledge" and only a few rods north of Neemes' camp, very thick, bluish-black limestone beds appear in the bank and dip into the lake. The water line intersects diagonally the strike of these thick limestone beds and as one walks along the shore one passes from syncline to anticline, rather closely spaced and regular in their succession and probably as strongly compressed as these heavy beds would allow. South of Neemes' camp the beach is covered with many boulders in which *Bellerophon, Trinucleus, Plectambonites* and other fossils are common. Above the bank apparent Trenton beds outcrop and many loose boulders are filled with Trenton fossils.

South of an east-west line passing approximately through Neemes' camp what are apparently Middle Ordovician strata have a topographic level about the same as massive Beekmantown north of that line. South of this hypothetical line, back in the woods about one-fourth of a mile southeast of the old Walker place, a quartzitic sandstone forms a low cliff. The scarp is farther east of the shore than that of the massive Beekmantown just north of Neemes' camp. There may be an east-west fault with an offset, in the vicinity of the camp, and with differential lateral displacement; or, as the topography affords reason for thinking, while there may be a fault the quartzite scarp south of it may owe its present more easterly recessive position to erosion of rocks left at a relatively higher topographic level after normal faulting.

The thick-bedded, bluish-black limestones just described are regarded as probably Black River, both from their lithology and stratigraphic relation to apparent Trenton rocks. It is not wholly certain whether they and the Trenton are part of the overriding mass, or are beneath it like the "Utica" farther north. In figure 11 they are represented as beneath. They may have participated in a thrust, or a reverse fault, and also be overthrust by older rocks.

The evidence afforded by the relations along the Champlain shore in Orwell favors the views:

1. That the Middle Ordovician strata (Trenton-Utica) are overlain by early Ordovician (Beekmantown) or possibly even older ("Potsdam") rocks;

2. That, as indicated by the absence of any but relatively gentle flexures, which indeed were probably due to much later deformation than that which produced its present superposition, the older rock was thrust bodily over the younger strata and now lies unconformably upon the latter along a thrust plane;

3. That a later crustal disturbance deformed the whole series, including the thrust plane, and caused irregular, gentle

flexures in the thick overthrust mass, which as now eroded displays the basal Ordovician and perhaps Upper Cambrian lying on the younger rocks;

4. That, at the time of the disturbance just mentioned, or later, there occurred some faulting with various degrees of displacement, involving the rocks both above and below the thrust plane;

5. That the major thrust plane which parted the thick mass of strata composing the Lower Ordovician of the region did not shear always at the same stratigraphic level, but cut through it so that the rupture was now through the Beekmantown and now through the "Potsdam."

These conclusions seemed reasonably clearly established before the relations in Orwell east of the shore were examined.

Relations west, northwest and southwest of Orwell village. East of the lake in the bottoms of ravines tributary to East Creek are many small exposures of friable slates and shales with easterly dip. Still farther east in the banks and bed of the North Branch of East Creek in various parts of its course the slates again outcrop and show frequent bands of interbedded black limestone. These slates were traced eastward along East Creek and the North Branch to the western margin of the limestone formations west of Orwell village.

One and a half miles west of the village, East Creek tumbles over the edge of limestone and cataracts across upturned slates. This place is the site of an old grist mill, formerly known as "Chittenden's Mill."

At the summit of the falls the rock is a dark blue or black limestone which breaks into splintery pieces. The beds strike N. about 38° E. and dip southeasterly. This limestone carries number of *Prasopora lycoperdon* on the eroded surface and when broken gave *Trinucleus* and linguloid shells. About half way down the cataract slopes in the brook bed a reading in the slates and interbedded limestones gave N. 77° E. There has clearly been disturbance.

About one mile northwest of Huff's Crossing, a few rods east of the railway track is a high scarp in massive, siliceous dolomite (see plate XXV). At the base are beds like those at the base of Mt. Independence and probably representing the "Potsdam" of Brainerd and Seely; but the slates on which this rock presumably rests, by analogy with conditions farther south on the lake shore, were not seen. Along the road east of the scarp are beds like those overlying the "Potsdam" at Mt. Independence.

In the bed and banks of the North Branch around Huff's Crossing are exposed higher beds of the Beekmantown formation, and three-fourths of a mile farther south some of these latter beds are exposed in numerous outcrops in the fields near the road.

PLATE XXV.

Scarp in the "Beekmantown" northwest of Huff's Crossing, along the erosional margin of the overlap by thrust of basal Ordovician on the Ordovician slate formation. At the base of the scarp, above the talus slope, is massive, quartzitic sandstone like that at the southern base of Mt. Independence, which was called "Potsdam" by Brainerd and Seely.

These exposures have been described by Brainerd and Seely. The blue limestone of their division D appears on the axis of the anticline carrying *Ophileta complanata, Maclureas* and other fossils. This member is succeeded on each limb by the other members of this division, although those on the east limb are most satisfactory for study. In the stream channels near Huff's Crossing divisions D and E appear and in addition the top of division C.

West of the highway bridge at Huff's Crossing the Beekmantown beds, which directly beneath the bridge lie in a flat position, as displayed in the south bank of the stream through a distance of about 300 yards show gentle undulations with apparently slight southerly pitch. Then appears an abrupt change from a moderate dip to one about 65° W. along a strike of about N. 25° E. About 60 or 70 feet of interstratified limestone and siliceous beds are exposed across their strike in the bed of the stream. About 100 paces west of these rocks are similar ones which show a somewhat puddled arrangement which is attributed to the disturbance which these rocks have suffered. Two hundred paces downstream, after an interval of clay, appear the blackish slates with limestone bands like those seen near the grist mill falls, westward at intervals along East Creek, and at the lake shore.

A mile and half south of these exposures, north of the road which runs westerly north of the grist mill falls, along the west edge of the woods and west of Beekmantown beds, were found numerous, well-preserved surface scrolls of *Maclurea magna* at numerous places and other outcrops of striped, bluish limestone like the Chazy as seen at other localities. West of this stratum are limestones carrying hosts of surface markings of fossils and which are regarded as probably representing the Trenton. These various rocks seem more metamorphosed than the Trenton rocks above and the slates below the dam at the grist mill and in some cases, at least, have a highly-inclined westerly dip.

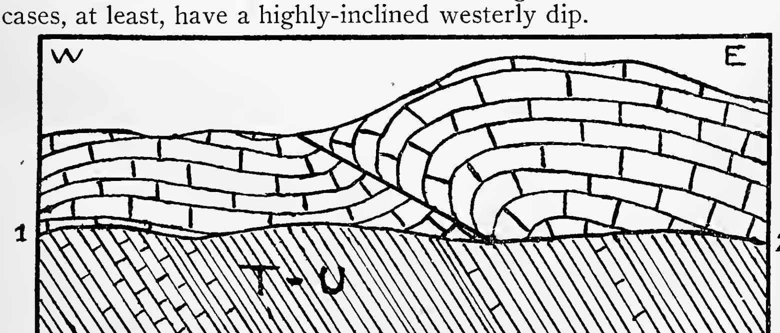


FIGURE 12. A section generalized to show interpretation of structure in the overthrust Lower Ordovician limestones (here largely "Beekmantown") west of Orwell village. The massive rocks were ruptured by reverse faults which were subsequently truncated by a thrust, 1-2. The rocks were carried westward over folded limestones and slates belonging to the Trenton-"Utica" formations of the present lake region. 1-2, thrust plane.

From the general local deformation shown along the western edge of this eroded anticline south of Huff's Crossing it would appear that there was a rupture following compression of the rocks composing it and that along the plane of rupture there was differential movement and friction which occasioned more flexing than these massive rocks usually underwent and which brought about some overturning. So far as observed in the massive strata found overlying the slate formation in this immediate region, strong flexure does not appear to have been their mode of deformation, from which fact the inference is drawn that the structure just described was due to friction and of the nature of a drag rather than one that preceded and initiated the break.

At the grist mill falls the eastern and western walls of the gorge are apparently composed of massive beds lying rather flat, and like those which extend with some interruption westward and southwestward toward the lake, and which form a noticeable scarp along the road to Montcalm Landing. From general field relations and lithology most of these rocks are correlated with the Beekmantown, although their exact position therein could not be made out with certainty. From the discordance in structure in the walls of the gorge it seems most probable that the massive so-called Beekmantown rests unconformably upon the slate formation and that it also once overlay the fossiliferous rocks at the summit of the falls. The conditions did not permit a good photograph. The massive strata seem not to be so severely deformed as the similar rocks lying north of them and it is regarded as probable that an east-west break lies between. The interpretation of probable general structure is shown in figure 12, which does not attempt to show the probable normal faulting just mentioned.

The massive magnesian rocks that extend westerly from the grist mill, about a half mile west of the dam are interrupted along the road and in the fields by slates which in one outcrop showed westerly dip. The field relations indicate that these slates are surrounded by the dolomite and have been exposed by the erosion of the latter. Westward the road to Montcalm Landing descends over a scarp in the dolomite to the Champlain clays that extend to the lake shore. This scarp is on a meridian a mile west of that on which is located the axis of the anticline south of Huff's Crossing. The rocks composing this scarp are apparently in somewhat interrupted surface continuity with other magnesian rocks which form the slopes and summit of a hill about one mile south of it, the upper beds of which are yellowish or somewhat chamois-colored rocks and which grade downward into other rocks which could not be correlated with certainty on account of drift and few exposures, but which towards the base contain cherty dolomites like those of Mt. Independence.

Additional considerations concerning the general structure of the region. From the outcrops and relations just described for the areas inland from the lake and west of Orwell village it seems that further support and suggestions may be drawn as to the interpretations to be put upon the structure of the region along the lake.

1. The structural relations at the grist mill gorge, taken with the general procumbent position of the massive strata; the difference apparent in the metamorphism of the rocks which are now in contiguity; and the patch of slates lying west of the grist mill which is seemingly surrounded with massive magnesian limestone beds and has therefore the character of an erosion outlier, give further support to the idea that the Beekmantown strata, and possibly older rocks, now rest on the slate formation and probably some Trenton rocks included or in addition, along a thrust plane.

2. That the massive overriding strata, either during or prior to translation, were broken along a reverse strike fault and that a slight buckle occurred east of the fracture with some folding down of the edges of the beds along the western margin of the block that was pushed against the adjacent beds on the west; and that possibly some Chazy and possibly still younger beds were involved in the frictional drag along this reverse fault plane.

3. That there may have been some warping or faulting later that dropped the strata between the gorge and the scarp north of Huff's Crossing and left the intervening beds at a lower level than those on each side of these faults, or in the trough of the warp, and thus preserved beds higher than the Beekmantown at the present erosion surface.

4. That the various scarps in the dolomite formation stand primarily for the major thrust relation which this formation bears to the slates; and that some structural features secondary to the thrust favored the erosion of the Beekmantown between the detached masses of these rocks near the lake shore and their sinuous inland margin which is often marked by scarps.

5. That the massive character of the overthrust rocks prevented much heaping up by reverse faulting under the compression.

6. That the plane of major thrust is now and probably was originally one of low angle to the horizontal.

Areas north, east and south of Orwell village. The Beekmantown rocks forming the anticline south of Huff's Crossing were traced eastward by scattered outcrops across their strike to the old stage road to Shoreham village and in places fossils were noted on the weathered surfaces. These fossils appeared as *Maclurea-* or *Ophileta*-like scrolls with others that resembled cephalopods in the shape of the outlines and in the presence of

septa. East of the stage road markings are less numerous and distinct and outcrops fewer on account of drift. On the basis of fossils and structure and also certain other exposures that will be described presently lying to the eastward, the beds over an east-west distance of a mile east of the road from Orwell village to Larrabee's Point are regarded as Beekmantown in age.

East of the road from Orwell village to Orwell depot, limestone outcrops are numerous and form a band a half mile wide resting against the western slope of Deignault Hill. *Maclurea magna* was found by the writer near the western edge of this band. East of the beds carrying this fossil the limestone shows abundant fossil markings on the weathered surfaces, but the rock is so altered that nothing distinct could be seen on fresh surfaces. At many places sections of shells both in the plane of the spiral and at right angles to the axis, strongly resemble *Pleurotomaria* and *Murchisonia.* A number of the more robust *Pleurotomaria*-like forms were abraded to the plane of the columella and left little doubt of their generic affinity. Spiral coils at right angles to the axis of the whorls were very common. Crinoid stems were frequent. From these characters the rock is regarded as probably of Trenton age. It bears closest lithological resemblance to other rock that will be described beyond in which still more characteristic fossils were found with those just described.

These limestone beds have a general north-northeast strike and seem to occur in somewhat undulating open folds. There is a prevailing easterly dip due to shearing deformation which has greatly obscured the stratification dip. At some places an apparent flattish position and at others a westerly dip of the bedding were observed.

The limestones just described are succeeded eastward at the surface by phyllites and schists on which they apparently rest, although no contact was seen. Along the road from Orwell village on the west slope of Deignault Hill outcrops of the phyllites intervene between others of limestone, but a short way beyond the eastern margin of the limestone is reached and may be followed in a north-northeasterly direction just west of the road running northerly at the top of the hill. The instance cited above was the only one noted northeast of Orwell village where the limestone has been eroded so as to expose a patch of the underlying phyllite. East of the limestone margin all is phyllite for a mile or more to the valley of the Lemon Fair River.

The limestones just described vary in degree of metamorphism along the strike and present certain interesting characters in their outcrops in proximity to the phyllite. Just east of the main village of Orwell, north of the road to Sudbury, the limestones are strongly sheared and are almost slates. Many surface exposures are "marbly" in appearance. Near the phyllite the

limestone is frequently seamed with many veinlets of calcite, a feature which was observed at many places in this general region where the limestone and phyllite are close together in surface outcrops, or where there is good reason to think that the phyllite is only a short distance beneath the limestone.

The limestones northeast of Orwell village continue along the strike south and southwest of the village with prevailing easterly dip which is for the most part a shearing deformation structure purely. One-fourth of a mile south of the village distinct easterly stratification dip is apparent and the rock carries sections of *Murchisonia*-like forms. In general the rock south of the village as far as the old stage road resembles the Trenton at the north.

West of the road the limestone seems to be more metamorphosed generally, is strongly sheared and seamed with calcite in many places, and often takes on a "marbly" appearance. At one place a sort of flow-cleavage structure seemed to have been developed nearly parallel to the bedding and both apparently were subsequently folded. The fold is now cut by two sets of fracture planes.

South of Orwell village the limestones give place easterly at the surface to phyllites, schists and slates which are the southward continuation of those in Deignault Hill. These terrigenous rocks form the high hills in the southern-central part of the township around Sunset Lake and its neighboring ponds, and extend into Benson township at the south. Two miles south-southwest of Orwell village, just east of the Benson-Orwell road, begins a series of scarps, which increase in altitude southward and which mark a normal fault displacement. At numerous places in the hills east of these scarps are cliffs that are interpreted as fault scarps and some of the ponds rest in what are apparently primarily faulted basins.

About a mile north of the Benson line on the downthrow side of the great fault the limestones along the valley of East Creek give place at the surface to phyllites which extend westerly as shown on the map. Over the phyllite lying west of the fault and in the high hills east of it no limestone was discovered.

The wider surface exposure of the phyllite formation at the south in Orwell township is to be associated with its present higher altitude and conditions which favored the erosion of limestone that once overlay it; for the field relations east and south of this spur of high land show that limestone of similar age and character to that which in Orwell rests against or on the schist at the west lies on entirely similar phyllite east of the spur and indicate the former extension of the limestone over the phyllite now forming the spur.

Eastern Orwell township. A strip of country about a mile and a half wide in the eastern part of Orwell township presents

many significant features. The northern part of this strip is now very largely buried by Champlain clays, but the southern part is hilly and affords many interesting outcrops which serve to bring out the general relations among the rock formations.

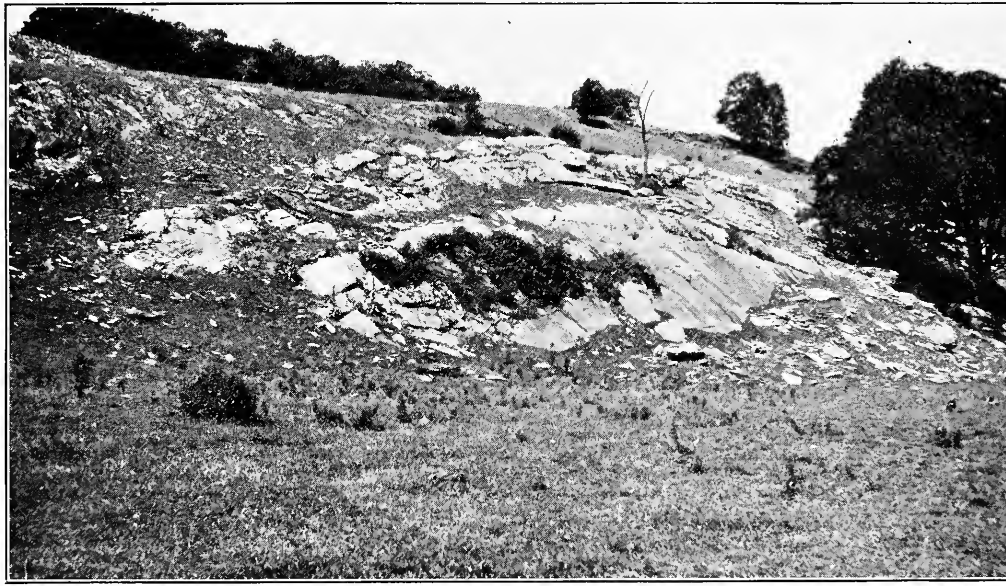
South of the Orwell-Sudbury road are two valleys separated by a low range of hills. Along the western valley extends the road from Abell corner to Bangall and Hortonville. The other valley is occupied by the head stream of Lemon Fair River and along its western margin is another road going also to Hortonville. Along these valleys and over the low range intervening between them the surface rock is largely limestone, which can be seen to have been much disturbed by folding and faulting and to have been severely sheared in most places. The prevailing rock is of a faded blue or gray color on weathered surfaces and dark blue or bluish-gray on fresh surfaces. So far as observed it does not often take on a "marbly" aspect south of the Orwell-Sudbury road. Fossils were found at many places in this limestone on the hills and in both valleys mentioned, chiefly on the weathered surface. They all have a similar aspect and consist of crinoid stems, scrolls representing shells of gastropods like those found northeast of Orwell village, sections in the planes of the axes of spirals resembling *Pleurotomaria* and *Murchisonia*, *Plectambonites, Orthis,* a doubtful streptelasmoid form, a small and a medium-sized *Orthoceras,* bryozoans like *Stictopora* and, on fresh surfaces, many specimens of *Trinucleus*. The most prolific localities were found on the adjoining farms of George W. Felton and Horton Farnum along a side hill just west of the eastern road mentioned above. Southeast and east of Farnum's, similar rock extends east of the road across the Lemon Fair valley and similar fossils were found at several places nearly to the Hyde Manor road.

For the most part the limestone just described, so far as the shearing structure permits observation, consists of beds of moderate thickness and in this and in general lithologic features as well, resembles the Trenton northeast of Orwell village and, in fact, also that along the lake near Neemes' camp. But it should be noted that metamorphism is clearly more pronounced in the areas east of the lake shore.

In Horton Farnum's pasture were seen some massive beds of limestone which from the field relations seemed to be inferior to the fossiliferous beds lying north and south of them. There was nothing seen to indicate whether the massive beds are of the same age as those surrounding them or older. See plate XXVI.

At various places along both valleys mentioned, on each side of both roads and within the low range of hills intervening, phyllite or quartzite emerges at the present surface from beneath the broken and eroded limestones. The map does not

PLATE XXVI.



A view to show fold in limestone on the farm of Horton Farnum in the valley of the Lemon Fair River in eastern Orwell. The view is towards the northwest. The fold is a north-south buckle with strong easterly pitch and the rock is sheared with easterly dip. The rocks in the fold shown did not yield fossils; but north and south in the fields many outcrops show markings of shells (see text), and excellent specimens of Trinucleus were obtained on fresh surfaces at several places.

attempt to show fully the fragmentary nature of these outcrops of terrigenous rocks. They appear sometimes as patches surrounded by limestone, sometimes as scarps along the strike on hill summits, sometimes but more rarely in sections across the strike in gulleys of erosion, and again as narrow bands, as though infaulted or infolded with the limestone. These terrigenous rocks are entirely similar to those of the Orwell hills and to those of the Sudbury hills lying to the eastward, and it was not possible to draw any distinctions among them on the basis of difference in age, or from their relations to the associated limestones.

North of the Orwell-Sudbury road the course of the Lemon Fair has been constrained and controlled in the process of the river's down-cutting by a few ledges which by the river's work and that of general erosion have been opened to view. Some of these ledges are of much interest.

Outcropping in the west bank of the Fair in the fields about one and a half miles north-northeast of Abell corner and exposed on the dip surface is the light blue limestone seen south of the Orwell-Sudbury road. In the east bank of the stream the beds are exposed along their edges and much of the rock is seen to be a strongly-sheared limestone having the character of a calcareous slate. Practically on the strike of these beds, a few rods north in the same bank and in a somewhat higher scarp, this sheared limestone takes on a "marbly" aspect and is infolded or infaulted with patches of chamois-colored, dolomitic rock. Near the base of the section light-colored, siliceous phyllites like those so frequent in the Orwell and Sudbury hills, and outcropping through the limestones lying between, emerge from beneath the marbly rocks and at one place a large solution hole has exposed the phyllite underlying the limestone. Northerly the sheared rock becomes still more "marbly" and lies above strongly-sheared, slaty limestone.

In this general vicinity the limestone or "marble" is filled with solution holes and channels along joints which give an impression that the limestone lies in disturbed relation to some stratum beneath.

The sheared "marble" extends through the fields eastward from the Fair for several rods and gives place at the surface to a sheared, light-blue rock like that noted on the west of the Fair. It is infolded with gray dolomite mentioned above.

The sheared blue rock and "marble" are thus seen apparently to pass into one another both along and across the strike in these exposures and apparently both have essentially the same relations to the gray or chamois-colored beds. The gray rock is also found south of the Orwell-Sudbury road, but its relations there are not impressive. Conditions similar to those just described for the rocks in the banks of the Fair and adjacent fields, north of the Sudbury road, prevail in the fields east and

south and need not be cited in detail. It may be noted that entirely similar types and relations extend through detached exposures southeastward to the west slope of Sudbury Hill below the stage road.

The field relations of the blue limestone or "marble" to the gray dolomite suggests that the dolomite is not interbedded with the other, but that it is usually above it and distinct from it. The examination of some of the exposures in which the two are infolded, or infaulted, might give the impression that the two are interbedded members of the same formation.

For some reason the rocks north of the Orwell-Sudbury road have been more severely altered and fossils in them now seem to be lacking.

RUTLAND COUNTY.

Benson Township.

(Whitehall topographic sheet.)

Topography. Hubbardton River and its head streams have cut their valleys below the level of 300 feet among the hills in the eastern part of the town, and a strip along the lake shore in the northwestern part a mile wide and a mile and a half long marks a small extension of the Champlain lowland into this area. Elsewhere Benson topography is typical of the foothill country west of the Taconic range.

Description of a section from Lake Champlain through Benson village to Bangall, near Hortonville. Extending from Benson Landing for a distance of one and a half miles eastward along the road from the landing to Benson village the section gives siliceous and magnesian limestones of Brainerd and Seely's Beekmantown formation. The beds form a gentle arch and near the lake dip at a low angle to the west.

At Benson Landing the Beekmantown rocks as exposed do not reach the lake shore, but a mile north at Stony Point they dip into the lake. A few rods east of Benson Landing are exposed in a low west-facing cliff in a ravine south of the road about 15 feet of dark, bluish-gray, siliceous limestone or dolomite, weathering light gray, in beds about two feet thick which dip gently to the west. About 20 rods to the east of this outcrop is a somewhat higher cliff in the ravine showing from the base about two-thirds the way up, massive beds of somewhat pitted, magnesian limestone which on fresh surfaces is mottled light and dark gray. Above these beds are a few feet of limestone showing many ridges parallel with the bedding. The dip is gently westward. Above these rocks, in and beside the road and perhaps 20 feet higher stratigraphically, near the junction with the Stony Point road and in the yard of the William White place, are exposed with westerly dip bluish-gray limestones frequently covered with

thick, reticulated, gray or reddish brown patches, which often show as shallow, ringed craterlets in relief which give the weathered surface a coarsely-pitted appearance. Among these pits and patches and also on the smoothly-weathered rock are scores of finely-coiled whorls of *Ophiletas* and some *Maclureas.* These fossiliferous beds are interstratified with layers of sandstone. Eastward about 200 yards along the road, dark, bluish-gray rock somewhat like that noted in the first cliff outcrops beside the road and a half mile east similar rock lies flat. Away from the lake the outcrops are few and mere patches in the drift. The precise sequence was therefore hard to determine; but it seemed clear that probably the fossiliferous rock represents the lowest subdivision of Brainerd and Seely's Division D, carrying *Ophileta complanata,* Vanuxem.

The magnesian limestones lying beneath the fossiliferous beds presumably represent Division C. All the rocks appear conformable, but the conditions do not permit minute comparison with similar rocks in the sections of Shoreham and Orwell.

Eastward along the road past the school house at Williamson corner and down the slope to a brook are occasional exposures which are not readily identified or correlated in their restricted outcrops.

South of the brook and the road are mud-colored slates which a few hundred feet eastward up the brook give place to bluish or dove-colored limestones intermingled with chamois-colored dolomite. The dove-colored rock carries dirty, yellowish patches and stripes often soiled to black and on its weathered surface at places afforded many small fragments of indeterminable fossils and two recognizable specimens of *Maclurea magna.* A reading gave the strike as N. 32° E. and the dip as 25° easterly.

East of these rocks a short distance, on the north side of the road, are limestones resembling the Trenton beds near Hortonville, which will be described presently. No fossils were found. East of these exposures, along the road, the rocks are slates, some of which are mud-colored, friable rocks like those mentioned above as occuring at the present surface farther west between probable Beekmantown and Chazy outcrops and which have what appears to be a distinguishable difference from most of the slates of the Benson hills. They have in fact a resemblance to certain slaty or shaly rocks which were noted farther north in Orwell, but which have not thus far been described in a special way. In some of the ravines tributary to East Creek in Orwell the friable shales did not appear precisely like the blacker so-called "Utica" and led to the suspicion that there is a series of beds in the formation that usually goes under the comprehensive name of "Utica" which is marked by less carbonaceous matter and whose members are of prevailingly different color. This idea seemed to receive some confirmation when mud-colored slates

were found west of the grist mill on East Creek along the road to Montcalm Landing and therefore lying west of the black, compact Trenton limestone and associated black slates at the dam and in the gorge of the creek and again when similar slates were found on the meridian of those west of the grist mill two miles to the south along the road to the lake that passes through Frank Charleton's farm, and also a mile south of here on the hill east of the Nefong farm (old Walker place) and east of the road from the Nefong farm to Benson Landing.

The mud-colored slates along the road from Benson Landing to Benson village lie on the general meridian of the various exposures of similar slates just mentioned as occurring in Orwell and are now regarded by the writer as the same. Along the Benson road they give place at the surface to black slates which have been called "Benson Black Slates." An actual transition was not noted. Outcrops of the mud-colored, friable slates, however, occur close to those of the black slates; but after the latter begin, going eastward, there do not appear to be any more outcrops of the lighter-colored and more friable slates. A similar relation obtains at the north; in northern Benson township, on the downthrow side of the great scarp along the Benson-Orwell road, a blackish slate is present and westward across East Creek the other slates appear.

The black slates continue eastward through Benson village and east of the village are succeeded by outcrops of lighter-colored, siliceous phyllites like those that are intermingled with the black phyllites of the Orwell, Benson and Sudbury hills. The black slates are not exactly like any of the terrigenous rocks that the writer has seen among the hills just mentioned. They also appear different from the mud-colored slates or shales at the west, not only in color, but in the fact of greater metamorphism. On the strike or meridian of the black slates farther south in Benson at Forbes Hill, however, occur the light-colored, siliceous phyllites and grits so common at the east, but this is not conclusive of similar general age for them and the black slates; for it will be shown that the probability is that terrigenous rocks have been overthrust on other terrigenous rocks in western Vermont and it apparently cannot be affirmed whether the black slates are beneath or on top in the examination of a surface section of such an overthrust. It seems probable, however, that the mud-colored, friable shales are of different age from the phyllites at the east in Benson village and eastward, and that they may belong to the same general formation that contains the black, limy, fossiliferous slates along the lake shore in Orwell, and also some of the Trenton rocks. If this is so, then the map of Orwell which shows the slate of the Orwell hills extending west of the scarp along the Benson-Orwell road should differentiate among the slates west of the scarp and show some of

them in the character used to represent the "Utica," just as was done west of the grist mill farther north. On such an interpretation some of the slates would be part of the mass that has been overridden and therefore probably of different age from the other terrigenous rock. It is, however, not easy to show any sharply dividing line at the present surface.

Continuing the section eastward from Benson village, outcrops are lacking east of the direct road from Orwell to Fairhaven along the road to "Spoke Hollow" or "Howard Hill corner." Due north of this road in the high hills around and west of Sunset Lake in the northern part of the township are phyllites and quartzites which have been described at another place, and south of these hills, across the valleys of the head streams of Hubbardton River, are entirely similar rocks which will be briefly mentioned again beyond. Similar rocks are found on Howard Hill.

On the southeastern slope of Howard Hill are exposures of limestone bearing strong resemblance to rocks which a little way to the eastward and elsewhere carry Trenton fossils. A half mile east along the road through Bangall to Hortonville, on each side of the road just northeast of Hall's corner, are ledges of undoubted Chazy showing the lithological characters of this rock and affording good samples of *Strephochaetus* and several recognizable specimens of *Maclurea magna,* besides fragments of other fossils.

Eastward from these ledges of Chazy, about half a mile, near the standpipe of the Hortonia Power Company, greatly-sheared, blue limestone has been blasted for the big conduit running to the power house, and still further east between Babbitt's corner and Hortonville, north and south of the road, are ledges of faded blue limestone which give evidence of arrangement in undulating folds with easterly dip which is sometimes that of stratification and sometimes very apparently that of shearing in westward dipping beds. Fossils are numerous on the weathered surfaces and include many small spirals and numerous sections in the plane of the axes of the spire of *Murchisonia-* and *Pleurotomaria*-like gastropods. In its fossil contents and in its other characters the rock is like that which at the north and northeast along the valley of the Lemon Fair and north of Horton Pond carries numerous Trenton fossils.

Along the section just described it will be seen that at the present surface there is wide separation by terrigenous rocks of the calcareous rocks near the lake from those near Bangall, but that the latter practically join the limestones of the valley of the Lemon Fair, and actually do join the rocks in the valley along the road that leads from Bangall to Abell's corner. Around Hortonville the phyllite formation frequently outcrops through the limestone by erosion of the latter. The section does not reveal any

Beekmantown rocks away from the lake region at the present surface.

The field relations of the rocks just described indicate that the calcareous strata east and west of Benson village lie on a formation of terrigenous rocks. That these latter rocks are all of similar age seems improbable. The phyllites on which rest the Chazy-Trenton rocks near Hortonville are entirely similar to those of some of the Benson hills and those found in the hills of Orwell and Sudbury; but nearer the lake the Beekmantown-Chazy-(Trenton?) beds may rest in part on phyllites like those at the east and in part on very different slates. See figure 14.

Some observations south and southeast of Benson village. South by east of Benson village along the road from the village through O'Donnell corner, black and lighter-colored phyllites in the association that has been so frequently mentioned outcrop at several places. At O'Donnell corner they occur together in the same ledge in the exposures near the dam. These rocks continue eastward and form the hills east of the road from Howard Hill to Fairhaven. For two miles along the Benson-Fairhaven road, from the junction of the Howard Hill road with it, the hills at the east drop by a high, steep scarp to the plain of Hubbardton River. This scarp is the counterpart of those along the Benson-Orwell road north of Benson. It diminishes in height southward and the Fairhaven road ascends from the plain and crosses the hill to Fairhaven. Near the top of the rise, west of the road, are ledges of greatly-brecciated blue limestone. Fossils have been destroyed, but the rock is lithologically like the Trenton as observed at the north. The apparent dip is eastward.

West of these outcrops, along the road that goes over Forbes Hill to Benson village, and north of it, are other ledges clearly dipping easterly and composed of gray dolomitic beds and light-blue limestone. The blue limestone is much altered and sheared. One much-weathered specimen which was identified as *Maclurea magna* was found and there seems little doubt that the beds belong to the Chazy. Westward and between these outcrops and Hubbardton River there appear to be other ledges of Chazy, but at the time they were examined circumstances did not permit a prolonged study.

Across Hubbardton River, along the road up the east slope of the hill, are phyllites like those in the hills east of the Fairhaven road and believed to be the continuation of them beneath the limestone that intervenes and to have been exposed by the erosion of the limestone. They continue along the road over Forbes Hill for a mile and a half where the limestones appear in the fields to the west of them and then north of them along the road towards Benson village. The latter rocks give place two and a half miles south of Benson village to the phyllites again which continue along the road towards the village. Limestone

was also noted forming detached hills in the plain of Hubbardton River.

The exposures just described south of Benson village, by a somewhat circuitous route it is true, connect the limestones on the Hortonville meridian with those near the lake. They carry the Chazy-Trenton beds nearer the lake rather than the Beekmantown away from it.

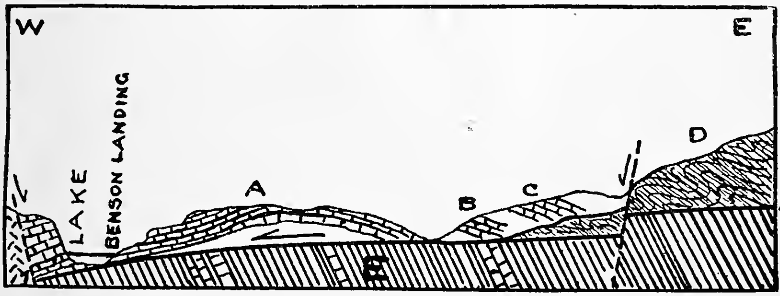


FIGURE 13. Writer's interpretation of relations east of Benson Landing. A, "Beekmantown," forming a low abraded anticline; B, Chazy, separated from A by a brook in which appear shales which are interpreted as exposures of the formations that have been overlapped by thrust; C, probably Trenton; D, black phyllite, probably Lower Cambrian, interpreted as unconformably subjacent to the Ordovician limestones. A thrust, 1-2, has cut through D and from it into the overlying limestones and all have been driven over E, Trenton-"Utica" slates. The rocks near the lake were subsequently dropped by normal faults as shown.

The field relations of all the exposures now described, though briefly, for Benson township indicate that the phyllite formation, as in Orwell, and as will be indicated presently as also in Sudbury and Brandon, once had a continuous covering of limestone strata which was either thrust or deposited upon it. There does not appear to be any essential difference in the terrigenous rocks over all this somewhat extensive area, except as indicated above for certain slates at the west. There seems to be no indication that the limestone appears from beneath the phyllite formation on account of folding and erosion or on account of thrust. On the contrary, the various areas of limestone are either purely erosion remnants, or thrust-erosion remnants, and whether outliers or inliers depends upon the age assigned to them and to the terrigenous formation on which they rest.

Short section north of Benson Landing. Before leaving the Benson area it seems desirable briefly to record some observations made north of Benson Landing.

One mile north of the landing, at Stony Point, siliceous limestone of arenaceous texture forms a cliff rising from the lake and lies nearly flat. Eastward from the shore surface deposits have covered the hard rock to a great extent, but through the sugar orchard east of Sibbald's cottage and eastward to the Chester Bishop place, are scattered ledges and the very gentle

dip and rock exposures indicate the northward continuation of the rocks and structure east of the Landing. In the northern section within a distance of about a mile were seen at intervals going eastward small exposures in the following sequence: 1, at the water's edge a rather coarse, siliceous dolomite; 2, tough sandstone, carrying many fragments of fossils looking like trilobite fragments; 3, siliceous limestone with ridges on the weathered edges; 4, blue limestone "conglomerate" with irregular fragments of a hue slightly different from that of the matrix; 5, layer with numerous whorls on the weathered surface; 6, drab or buff-colored dolomites.

From this sequence, although outcrops were usually limited in number except at the east, it was concluded that this flat arch is composed largely of Brainerd and Seely's Division D, with possibly some of C at the west and some of E at the east where the dolomite strongly resembles that associated with the blue limestone of the Chazy. So far as observed the arch was not broken or eroded to expose any slates through it.

RUTLAND COUNTY.

Sudbury Township.

(Brandon topographic sheet.)

Topography. This township includes most of the spur of high land which forms the northern end of the Taconic range. On the west and northwest the spur is bounded by the valley of the Lemon Fair River, which is a southward extension of the Champlain lowland between the Taconic hills. On the east and northeast the spur is bounded by the low, swampy flood plain of Otter Creek, along which the Champlain lowland merges with the Vermont valley.

The spur falls off gradually in altitude northward into the low schist ridge of Whiting, which is flanked on the east and west by limestone. There are certain structural features both within the spur and along its margins which will be described in detail beyond.

General geological features. As one passes eastward from the lake region through the Taconic range towards the Green Mountains the confusion in field relations and the difficulty of interpretation increase. The field worker experiences the need of multiplicity of detail in critical relations in order to feel at all sure of his views of structure and even then it will happen that two persons will arrive at quite different conclusions with respect to the meaning of presumably critical relations or will stress quite different things as being of importance. It soon becomes apparent to the student of the metamorphosed and greatly deformed rocks lying east of the lake that the region must be viewed more or less as one grand unit in order to see

into the meaning of its smallest part. Recognition of the direction of the road which one must travel to get anywhere perhaps will be conceded as an important step leading towards the destination.

North and south of Sudbury village. The sheared blue limestones and marble and associated gray dolomite in the valley of the Lemon Fair River in eastern Orwell township that have been described, continue into Sudbury township and give place eastward to the terrigenous rocks of the Sudbury hills, which are practically continuous northward with a low ridge of similar rocks extending northward into Whiting township and southward join with the entirely similar rocks of Hubbardton. The map shows connection across the ridge of the limestone of the Lemon Fair valley with that of Otter Creek. Whether one showed the area, which on the writer's map represents a surface connection of the limestones, as there shown, or as schist, would depend upon what outcrops were stressed, as will be seen presently; for it appears that schist lies beneath limestone in the area and also outcrops through it. It will be convenient to say that both are practically continuous, which, though literally impossible, when so stated conveys important ideas. The schists outcrop everywhere along the road from Webster's corner in Sudbury nearly to Whiting village, also westward nearly to Ketcham corner, where they appear on the meridan marked by the marbles and sheared limestones farther south. Eastward they extend one-third of a mile from Webster's corner along the road to Brandon and are then interrupted by the limestone for a short distance. At this interruption the limestone is really a calcareous slate as shown in pits along the road and in fields nearby and might be mistaken for the schist or phyllite formation if hastily examined. A little farther east the schist appears in the road, east of the school house, but is again bounded by the limestone north and south.

West of Sudbury Hill is an old road across the flats that runs from the village to Ketcham's corner. East and west of this old road are detached, knoll-like patches of limestone or "marble" with associated gray dolomite projecting through the clay of the old "lake" bottom and apparently to be regarded as practically continuous westward beneath the clay with the similar rocks described above as outcropping in the banks of the Lemon Fair; but whether continuous with or surrounded completely by limestone beneath the clay, or whether partly surrounded by schist, could not be determined for they are now simply islands in the clay. These exposures show varying proportions of either sheared blue limestone, or "marble," with gray dolomite. On the west side of the main Sudbury road, on the west slope of the hill below the village, the rock is often a whitish or salmon-pink sheared "marble" and this and the rocks in general along the old

road mentioned are entirely similar to those which extend around the northern end of the schist spur and join with others at the east. Directly west of Sudbury church the sheared "marble" is overlain by a mass of thick, blocky, gray dolomite through which the marble peeks at places and the structure was made out as probably that of a local syncline of "marble" holding the superjacent dolomite.

South of the Sudbury church is sheared "marble" and associated dolomite and this association in general continues along the scarp slope east of the Hyde Manor road as far as Hyde Manor. South of the Manor the "marbly" rock gives place apparently along the strike to light blue limestones mostly sheared into slaty-looking rocks and these, except for an occasional tongue or patch of schist near the summit of the slope, and with obvious faults and flexures, are continuous with the sheared blue limestones, dovetailed with tongues of schist and carrying Trenton fossils, north of Horton Pond and extending westward across the upper valley of the Lemon Fair.

Directly east of Hyde Manor, along a brook that descends from the hill, the phyllite formation has been exposed by erosion of the limestone and is continuous eastward at the surface with that of Government Hill. South of the road from Hyde Manor over the hill to the Huff Pond road occur patches of limestone surrounded wholly or partly by schist and the latter outcrops through the limestone at the summit of the scarp slope just west as a gray, pyritiferous rock much like that seen in the valley of Sugar Hollow Brook east of Brandon in association with phyllites quite similar to those of the hill east of Hyde Manor.

An east-west section along a parallel about 300 rods north of Sudbury church gives sheared blue limestone just east of the stage road, which is succeeded eastward up the hill slope by phyllite, and this in turn by limestone. But along this section erosion has left few or no remnants of limestone on the higher slopes, and eastward over the hill for a mile and a half all is schist or quartzite.

At the northern end of the Sudbury spur, about a mile northeast of the church, is an instructive east-west section along which erosion has produced a mutually interrupted series of outcrops of limestone and schist, as now exposed, and which is indicative of what was probably once the condition over all the higher portion of the spur to the southward.

One and a fourth miles north of Sudbury church, in a gulley beside the main stage road, is sheared blue limestone. Eastward up the slope this is succeeded by schist which is the northward continuation of similar rock on the northwest slope of Government Hill where it is often intermingled with patches of quartzite. The schist forms a scarp which is topped by limestone. The scarp is regarded as the northward expression of normal displacements

on the west of Government Hill, of which the one east and north of Hyde Manor is the most clearly defined at the present time. The limestone topping the scarp just referred to is a slaty, sheared, blue rock in places and "marbly" in others. It is succeeded eastward by schist with contact concealed, but with the two rocks only 9 paces apart. Then a short distance eastward is the sheared blue limestone again with "marbly" aspect, then schist once more, then sheared blue limestone with some dolomite mixed with it, then schist, and once more sheared "marble" mixed with dolomite, then "marble" which joins at the present surface with extensive exposures of similar rock lying eastward and northward to the road. On the map the phyllite or schist is shown dove-tailing with the limestone along the section just described, but such arrangement is somewhat schematic. The implication is that the calcareous formation is superjacent to the terrigenous rocks as is the case in the areas lying to the west. This relation seems to be capable of reasonable proof by the means so far employed without paying much special attention to differences of dip and strike in the associated rocks. Many areas of the "marbly" rock at the east of the section just described are pinkish in color like that west of Sudbury church. Dolomite is intermingled with it at various places and it passes laterally into blue, sheared limestone.

East of the section just described, and east of the north-south road that joins the Brandon road ("Otter Creek road"), near the school house, are four large, conspicuous hills which are composed largely of sheared limestones and marbles, and all show, at some places more than at others, gray dolomite resting on the blue limestone or marble in patches and intermingled without any regularity.

It is reasonably apparent that the north end of this spur of the Taconic range in Sudbury now has metamorphosed limestones lying on the schist formation and that the latter has been exposed at many places by erosion of the limestone, while the limestone has been preserved from erosion at certain places by protection through folding or faulting. South of the section at the north end of the spur which was just described to demonstrate these relations, and to show that the conditions prevailing west of the Sudbury hills also occur in them, limestone has not been found by the writer within this spur in the township of Sudbury, except east of Hyde Manor along the lower faulted portion of the western slope of Government Hill, where the limestone which tops the considerable scarp east of the Manor extends easterly to the Huff Pond road.

The question of the age of the sheared, blue limestones and marbles on the western, northern and northeastern slopes of the Sudbury spur apparently cannot be readily affirmed from fossils, as most of these rocks are extensively altered. None was found

in them by the writer. The question is complicated by the presence of disturbances, some of which seem fairly easily defined as to character, while others are very difficult to explain. There are, however, some considerations which serve to establish the identity of some of the limestone on the basis of probability.

The fossiliferous Trenton limestones in the southeastern part of Orwell township, as discussed above, pass eastward across the low, hilly land between the head stream of the Lemon Fair and Horton Pond and join at the present surface with the sheared blue and slaty limestones south of Hyde Manor, while these pass northward along the face of and on top of the scarp east of the Hyde Manor road through Sudbury village from which area, when traced northeastward, they join with the limestone exposures at the northern end of the Taconic spur and when traced northwestward they join with the sheared blue limestones and "marbles" in the valley of the Lemon Fair. The latter are to all appearances the northern continuation of the fossiliferous limestones to the south of them. Over this considerable area, therefore, these various rocks may seemingly be traced with unimportant surface interruptions into each other. Added to this is the important fact that at scores of places these various rocks have substantially the same relation to an underlying schist-phyllite formation, which is throughout essentially the same in its characters. Moreover, there is associated with all these various rocks a singularly similar gray dolomite which has held to a more uniform appearance in the different localities, for some reason or other, and which lies on the fossiliferous as well as the metamorphic rocks, although seemingly more abundant at the east. Further, the strong indications of normal displacement on the west of Sudbury Hill afford explanation of any apparent discontinuity at the present surface. The lithological differences among these calcareous rocks require explanation, especially on the assumption that the various rocks are essentially the same; such differences might be seized upon to show that the rocks could hardly be the same. But any effort to explain the differences may be postponed for the present.

Description of an irregular or composite section across the northern end of the Taconic range passing through Government Hill. The section begins for sake of completeness at the Hyde Manor road and extends to the eastern boundary of the township of Sudbury, across the schist formation.

At this point it will be convenient to call special attention to and to discuss briefly certain lithological differences shown by the members of the schist formation. Some of the terrigenous rocks making up this formation are distinctly schistose, but perhaps most of them are better called phyllites than schists because, though obviously altered, crystalline rocks and while generically speaking they are schists, they are prevailingly rather fine-grained

PLATE XXVII.

Trenton limestone beds, valley of the Lemon Fair in Orwell. Sudbury hills in the distance. The limestone beds in this photograph show a structure very characteristic of the calcareous rocks of the region and which has apparently been developed as a result of shearing strain. Here the dip of the induced structure is in the same direction as that of the beds; but in other cases this dip may appear in westward dipping beds. The dip of beds in surface sections is often hard to make out on account of this internal deformation.

and do not show their minerals conspicuously when viewed with the naked eye, except where they carry the large crystals of pyrite which have been mentioned, or other phenocrysts. In the older descriptions of these fine-grained, micaceous rocks they were called "hydromica schists." Many, perhaps most, of these phyllites are black and many are light-colored, fissile rocks, cleaving somewhat like slate, but more brittle and chipping into many small pieces. A coppery-colored stain is abundant in both, but usually more apparent on the lighter-colored variety. The pyrite seems to be much more characteristic of the black phyllites. It occurs, however, in some of the other terrigenous rocks of this formation.

True slates are not abundant at the present surface over the Sudbury hills, although they occur there and in the Orwell hills as well. They have not been found good enough to quarry profitably. Occasionally among these rocks there occurs a very black, carbonaceous phyllite, rich in small pyrite grains, and rather restricted in its lateral and horizontal extent. Quartzite is abundant, sometimes in scattered small patches, but at other places continuous at the surface, or practically so, over considerable areas. In a number of places white vein quartz in irregular seams and patches is abundant within the quartzite. Some of the black, pyritiferous phyllites, gritty schistose quartzites, and more compact or massive quartzites are indistinguishable from similar rocks found east of Brandon in the ridge west of Sugar Hollow and near the base of the margin of the plateau.

While there is thus often a manifest difference in general surface aspect of ledges in close proximity, both in color and lithology, after an examination of hundreds of outcrops over the Sudbury and Orwell hills and in other parts of the Taconic range, the writer has failed to find any positive criteria by which to separate one from another on the basis of age. The structural relations and other considerations seem to afford sufficient explanation of the variations seen at the present surface. In the high scarps on the west of the hills in Orwell and northern Benson, massive quartzite is interbedded with black phyllites and other rocks which could not be satisfactorily inspected on these precipitous scarps; but which together had an aspect very similar to that given by a surface section across the summits of the ranges lying east and similar to the association of phyllite and quartzite east of Brandon.

As may be mentioned again beyond there appears no good reason for regarding the phyllites along the low ridge that extends from Sudbury into Whiting as different from those in the Sudbury hills, although along the Sudbury-Whiting road the light-colored variety is rather in predominance. In a brook two miles northwest of Whiting village occurs the same quartzite

with its nests of white vein quartz that is so conspicuous on Government Hill.

One-half mile north of Hyde Manor and east of the stage road is a scarp. The steepest portion of the face near the top is a sheared "marble." This continues over the summit and eastward is covered at places with the gray dolomite. The calcareous rocks extend from the scarp eastward for about one-third of a mile to the Huff Pond road. At the base of the scarp at places near Hyde Manor the dolomite has a position that might suggest an interbedded relation to the "marble," but as the superjacent position of the dolomite is more apparent the relations at the Manor are interpreted as due to faulting as shown in figure 14.

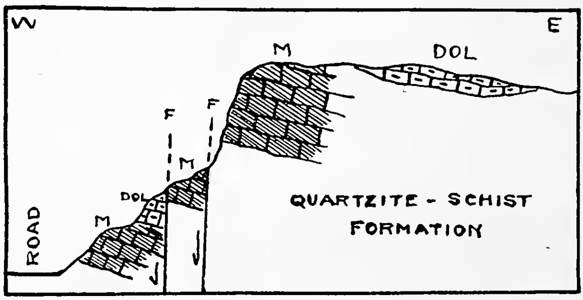


FIGURE 14. Section just north of Hyde Manor, somewhat generalized as to attitude of beds, showing gray dolomite as probably faulted with sheared limestone, which produces appearance of being interbedded. The calcareous rocks are shown as being underlain by the quartzite-schist formation of the Sudbury hills.

A little south of the section as just begun, along the cross-road from the Manor to the Huff Pond road, and also east of the main road from Sudbury village to the pond, on the western slope of Government Hill, are black phyllites with bedding unusually distinct and striking nearly east and west, N. about 70° E., and farther up the slope near the summit thick-bedded quartzite shows much disturbance from the prevailing strike of the rocks roundabout. A reading here gave N. 70° W.

The surface rock on the western slope of Government Hill is prevailingly a blackish phyllite, with some patches of quartzite, but the latter forms most of the ledges north and south along the summit of the hill, and in places carries much vein quartz in irregular seams and bunches.

Government Hill descends over quartzite by a gentle slope of irregular surface on the east about 150 feet through a distance of less than one-third of a mile. Then comes an ill-defined scarp, which does not appear on the topographic map, with the black phyllite at its base and quartzite forming the higher portion and summit. Eastward this hill descends over quartzite by irregular surface to a swamp with a sharp scarp facing west on the

east of the swamp and with the black phyllite at the base and quartzite again at the succeeding summit. Then another easterly slope to a swamp with another scarp, sharper if anything than those just mentioned and exhibiting similar geological relations.

East of the eastern slope of Government Hill, the section as thus far described, is either through a dense, swampy tangle or thick woods and very difficult to traverse, but while the ledges are much covered with decaying vegetation the succession can be made out.

At the east of the spur in the high hill north of Dolan's house, two-thirds of a mile north-northeast of Landon's corner, the quartzite seems thinner than farther west. This hill has a sharp scarp on the east which is clearly visible from the road running northerly from "Pond Hole" school house. Between the base of the scarp and the road are abundant ledges of the black phyllite with patches of quartzitic graywacke and some of the lighter-colored phyllite intermingled with it. The map shows the fault marked by the scarp just described. The schist has been dropped. North and south on the downthrow side it gives place at the surface to exposures of sheared blue limestone and dolomite. At the north the latter lie now in great confusion and in places near the schist are much mashed and broken. Eastward across the road and brook the phyllite is succeeded by sheared and foliated "marble," or blue limestone, and associated dolomite.

From the scarp just described a probable fault extends northwesterly between the phyllite and limestone towards the northern end of the Sudbury spur. This is marked by a scarp for some distance, with a swamp at its base. The limestones east of the north-south fault just mentioned are on a meridian occupied by "Long Swamp" at the north; while those north of the probable fault running northwesterly lie on the meridian of and are identical with those which have been described as forming the high hills northeast of the Sudbury spur.

From the facts now recited, of the occurrence east of Sudbury church along the strike of the sheared "marble" at Hyde Manor of black phyllite like that east of this marble at the base of Government Hill, and of the occurrence of similar phyllite along the strike of the "marble" west of Burr Pond and north of Horton Pond, and of field relations in Sudbury village and northeast of it, as well as at other places, it is apparent that the phyllite is, along the margins of the Sudbury hills, subjacent to limestones that can be rather satisfactorily traced into one another at the present surface and which present similar features and associations. And a field examination leaves a strong impression, almost no doubt, that the different members of the terrigenous formation are components of a formational unit.

Composite section from the phyllites of southern Orwell across the Taconic range to Otter Creek in Brandon. This section, like the preceding one, is a broad band or belt from west to east.

Beginning in the phyllite formation in southern Orwell, for sake of completeness, the section passes from these phyllites over a band of limestone, which is the northern extension of the Chazy-Trenton rocks of Bangall in Benson township, with some irregular outcroppings of phyllite through the limestone, then over phyllites which are the northern extension of those in Hortonville, then over a succession of limestone and phyllite bands dovetailed in with each other, the limestones carrying probable Trenton fossils, to the phyllites west and north of Burr Pond. The black and associated light-colored phyllites forming the hill north-northwest of Burr Pond are succeeded eastward at the eastern base of the hill by massive quartzite with prominent ledges just east of the brook that feeds Burr Pond, between the brook and the road. Across the road is a softened scarp, facing west, then for a mile schists with patches of quartzite to another scarp that faces east and at the base of which is the sheared, blue limestone extending south of "Pond Hole." This scarp is the southward continuation of that which was described in the preceding section as bounding the phyllite and quartzite formation on the east. The fault which this scarp marks can be followed southward with diminished scarp and passes just east of High Pond, about two miles south of "Pond Hole." The map does not attempt to show a number of scarps, which presumably mark fault lines through these hills, because the writer wished to avoid a prejudicial impression which often comes from seeing many such features represented on a map whose area is so small in comparison with that of the actual territory pictured. An examination of the region would be sufficient to show how much these rocks have been disturbed and the extent to which their present surface succession and arrangement may be explained by disturbance.

Taking up the description at a point one-fourth of a mile north of High Pond, along the fault line just mentioned as extending south of "Pond Hole," the section eastward is over black phyllites on the west slope of the hill called "Stiles Mountain"[1] on the map, then over massive quartzite in prominent ledges through the woods along the east slope to the road, then across the road and on phyllites and quartzites over a succession of steep, scarp-like slopes facing west and gentle ones facing east, including those of Stiles Mountain proper, for a mile and a half to an old wood road. East of this road on the west of Castle Mountain is a very steep scarp at whose base a brook runs northerly. In the bed of this brook, perhaps 100 rods from its junction with another brook, massive quartzite rests on black

[1] The name Stiles Mountain, according to the residents, really belongs to the second high hill east of this one.

phyllite on the downthrow side of the fault, which is marked by the scarp under which the brook flows. The west scarp of Castle Mountain ascends over phyllites, which are succeeded at the summit and down the eastern slope of the mountain by phyllites and quartzite. Midway down the eastern slope are patches of gray, siliceous dolomite of arenaceous texture. The phyllites with quartzite continue to the base of the hill and are succeeded eastward at the edge of the valley by marble and blue limestone with associated gray dolomite. Along the section just described the light-colored phyllites are frequent at more or less regular intervals, but without any defined order.

Over the high hills along the southern boundary of Sudbury, from Horton Pond to the valley of Otter Creek, which were surveyed with care, no limestone was found by the writer except the siliceous dolomite mentioned as occurring in patches on the eastern slope of Castle Mountain. Further evidence that the limestone once rested on the terrigenous rocks is however obtained from relations shown along the valley of the brook that flows east in the hollow north of Stiles Mountain (proper) and Castle Mountain to join Otter Creek. Along this valley, as shown on the map, and separated by the phyllites and quartzites from the limestones of the valley of Otter Creek, and surrounded by the terrigenous rocks, are patches of sheared, bluish marble. The valley of the brook is presumably a small, east-west trough-faulted basin separating the hills north and south of it, and the limestone has been dropped between them.

The road from Bressee Mill to Brandon, a half mile south of the Dean farm, skirts the eastern base of a scarp in greatly sheared and contorted marble, which at the top of the scarp rests on quartzitic schist, while south of this scarp on both sides of the road to Bressee Mill are ledges of massive quartzite. There is a scarp running west-northwest from the road south of Dean's place and which extends from the edge of the Otter Creek valley to the embayment which is shown on the map as bounded rather symmetrically by fault displacements. This scarp probably marks a normal displacement and, although phyllite occurs on the downthrow side, it substantially separates limestone on the north from the terrigenous rocks of the hills.

The embayment mentioned, in which the limestone now extends southward at the surface between higher masses of phyllite, is bounded at the south by another scarp along the high tension line of the Hortonia Power Company, just north of which is a considerable swamp. South of these faults as just described as bounding the phyllite hills on the north, the limestone has been eroded on the upthrow side, except as shown on the map. North of them the limestone has been preserved, as shown, by downfaulting. On the northeast the Taconic hills are thus separated from the low land west of Otter Creek by well-marked normal fault displacements.

RUTLAND COUNTY.

Brandon Township.

(Brandon topographic sheet.)

Topography. The short spur of the Taconic range which includes "Stiles Mountain" and "Castle Mountain," whose geology was described under Sudbury, really belongs in Brandon township. Bordering this spur on the east is the low, level flood-plain of Otter Creek which extends into the northwestern part of the township and there is largely occupied by extensive, wooded swamps.

Except for a short distance near Brandon the Rutland R. R. follows the eastern margin of the plain. At various places ledges emerge from the plain as detached knolls, some of which are of considerable size; but for the most part along the creek the hard rock is hidden.

Along the eastern edge of the plain are low hills which offer nearly continuous exposures. On the whole the land rises eastward to form a somewhat rolling upland which, with some interruptions due to ancient dissection of the rock surface, passes into the foothills of the Green Mountain plateau. The Neshobe River and other streams have in recent times terraced an old sand plain that marks a period of glacial flooding or a submergence of the old rock valleys among the hills east of Brandon village. East of these streams the land rises more rapidly to the western edge of the plateau, but east of Brandon a ridge of intermediate elevation is separated from the steep scarps that border the plateau by the valley of Sugar Hollow Brook. In general, however, a strip of hilly and mountainous land about two miles wide extends in a north-south direction through the eastern part of the township.

General geological features. In Brandon township many of the rocks are marked and masked by still greater metamorphism than that shown by the rocks of Sudbury. But this feature is not true of all. In this township appears a series of beds that has not been identified in Sudbury and is the northern continuation of the "interbedded series" of the Lower Cambrian that will be discussed in connection with different parts of the Vermont valley at the south. In their well-preserved, bedded character and in other ways these rocks are in contrast to most of the other calcareous rocks of the Brandon area, which, as exposed both at the surface and in the quarries, give evidence of great dynamic stresses in the flow structures which they exhibit and in the obvious crushing and crystallization which they have undergone.

With the terrigenous rocks in many cases there does not appear to be distinguishable difference between those in the Sudbury-Orwell hills and similar types lying east of Brandon village;

PLATE XXVIII.

Terraces cut by Neshobe River west of Forestdale, near Brandon, in probable delta deposits, made either in a glacial lake or in an inland extension of the sea. These deposits now extend southward and westward through Brandon in rock valleys among hills composed of marbles and overlying interbedded members of the Lower Cambrian series of the region. The meander in the foreground exposes (not visible in plate) and is controlled by the beds of dolomite and quartzite which lie beneath those shown in plate XXXI. Green Mountain plateau in the distance.

but in the scarps of the western edge of the plateau and at other places along its edge, quartzite and arkose have sometimes been sheared into more or less foliated rocks.

General relations west of Brandon village. The sheared "marbly" rocks and sheared blue limestone with associated gray dolomite which compose the conspicuous hills in the northeastern part of Sudbury township in some cases lie in faulted position against the rocks that underlie the plain of Otter Creek, along which a surface area two miles wide with few exposures, separates the rocks on the west from those on the east of the creek, although there are a few detached outcrops, or islands, which serve in a measure to bridge the gap. The easternmost of these islands is at the southern extremity of "Long Swamp" and lies on the meridian which farther north marks the western edge of practically continuous surface exposures northwest of Brandon, which edge is two miles east of the meridian along which lie the conspicuous hills of Sudbury township mentioned above.

South of "Long Swamp" and north of the fault at the northern end of the Taconic hills which lie southwest of Brandon village, a continuous surface section from west to east spans the distance between the two meridians and joins fairly closely with other exposures which carry the limestones to the meridian of Brandon village, while farther south detached exposures, similar to those at the north, outcrop in the plain of Otter Creek, which owing to the course of the creek is here two miles or more east of the plain in the northwestern part of the township, and carry the section in limestone to a meridian which passes a mile east of Brandon village.

The above-described relations may assist somewhat in understanding the geological features around Brandon village.

The calcareous rocks of the islands along the plain of Otter Creek and along the continuous east-west exposure south of "Long Swamp," except some rocks which will be mentioned later, are entirely similar to those which have been described for the northern end of the Taconic spur in Sudbury. Making due allowance for such disturbances as these rocks have experienced since their present general relation to the phyllite formation had been established, it has seemed possible to trace rather satisfactorily the counterparts of the fossiliferous beds on the west side of the Taconic spur around its northern end into the Brandon area. Two considerations seem especially to warrant the propriety of such procedure:

1. The invariable occurrence of a similar association of gray dolomite with marble or blue limestone in all fairly extensive exposures.

2. The fact that if we view the transition area from Sudbury into Brandon broadly, that is, so as to include an east-west section as wide as the township of Brandon is long from north

to south, we have rocks on the eastern side of the Taconic spur having the same relation to the terrigenous formation as that which obtains on the western side and at the northern end, and not to be disguised by any faulting which has occurred on the east.

The latter consideration seems to give further indication that the same terrigenous formation that composes the Taconic spur is present at depth beneath the marbles and their associated dolomite beds of the Champlain lowland around Brandon village. On such an assumption it becomes easy to account for the similarity of the terrigenous rocks east of Brandon to those of the Taconic spur and to support certain ideas of the down-faulted character of the Vermont valley around Brandon and in other places which will be offered later. If such an assumption should prove plausible it must have far reaching significance in the interpretation of the structure of the region.

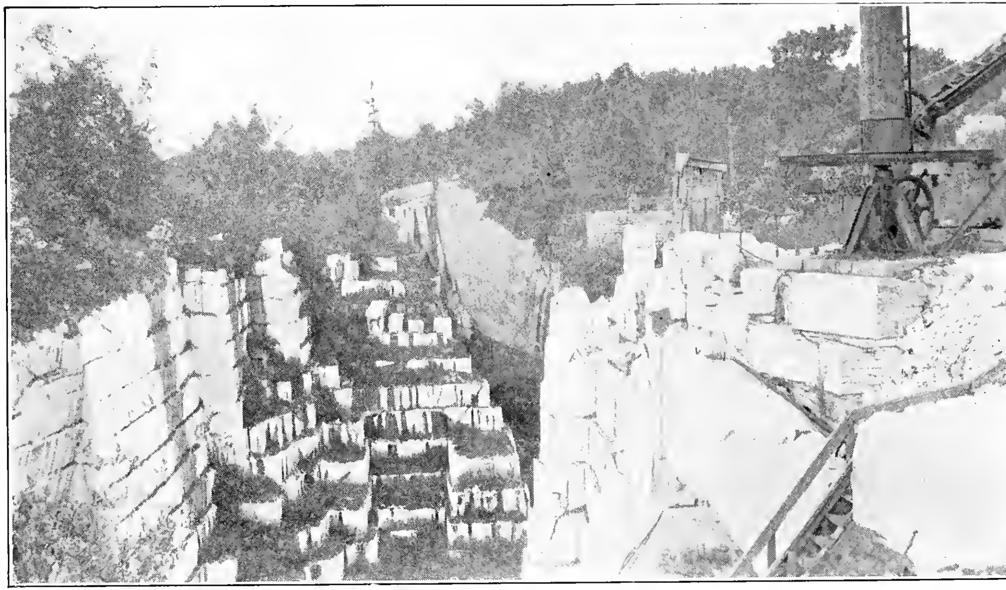
The gray dolomite which has so frequently been mentioned as occurring in association with the sheared blue limestone or the marble rocks west of Brandon seems to be quite distinct from any member of the interbedded series which, as will be described later, consists of interbedded dolomitic limestones, calcareous quartzites, and quartzites, and perhaps other dolomite not strictly interbedded, like those occurring throughout the Vermont valley; and this distinction holds even in those places where the interbedded series also is now clearly present above the marble.

In the Brandon area there are exposures in which this gray dolomite is associated with a dove-colored rock, which is striped precisely like the Chazy rock seen at Bangall in Benson township, where it carries well-defined, probably middle, Chazy fossils, and like that seen west of Bennington in southern Shaftsbury, and elsewhere. One of the places near Brandon where this striped rock may be seen to good advantage is one and a half miles north of the village, about 300 rods west of the old race course. The rock here is so greatly altered that all traces of organic remains have been obliterated and do not appear with any definite characters even in weathered outcrops. The stratum showing this association continues southward to the angle of the roads and across the west road. It also occurs a mile south, west of the village, north of the "Otter Creek road," and at other places west of the village.

This association had also been noted at places in Sudbury, and at other places less distinctly in the Brandon area; but what now seems its probable significance was not grasped until the examination of the Brandon area was well under way and until the Brandon region had been reviewed in the light of relations which are shown at the west.

If this association of dove-colored rock and gray dolomite is the Chazy, as now seems to the writer likely, it appears to be

PLATE XXIX.



View of the "Brandon Italian Marble" quarry one-half mile south of Brandon village, showing in the east face of the quarry the smooth and rounded surface of an included mass of dolomitic limestone.

significant that it so often lies apparently on the marble, or above the sheared blue limestone, as the case may be. In the vicinity of Brandon, except where the interbedded series of dolomite and quartzite has overlapped it, the dove-colored rock and its dolomite roughly alternate across the strike with the marble, with the result that each of these strata forms an indistinct band or "vein" running somewhat parallel with the other north and south. A greater width of the marble "veins" is now seen along the meridians where this rock is quarried.

The marble bands are not, however, homogeneous in their composition. Every quarry of any size in this area shows some dolomite, either on top of the marble or as infolded blocks or other involved fragments in the quarry rock. Where these dolomitic or "flinty" masses are discovered in the course of quarrying they usually halt the work at that point and drive the quarrying in a new direction. In Huntley's quarry at Leicester Junction, where the rock is burned for lime, pink marble just like that northeast of the Sudbury spur has sheared each side of a huge block of dolomite which shows in the north and south faces of the quarry. This dolomite is often a drab-colored rock and frequently occurs in close association with interbedded dolomites and quartzites. In the quarries generally all bedded structure is greatly obscured or obliterated and profound dynamic effects, such as mashing, flowage and crystallization, are everywhere manifest.

The explanation of the relations of the gray dolomite and its associated dove-colored rock to the marble around Brandon seemingly must account for the present apparent superposition of the former in so many places on the assumption that the former is Chazy and the latter probably Trenton. The agency of reverse faulting or thrusting at once comes to mind. The effect of such deformation would be to elevate the Chazy against the younger rock and carry the former over the latter. If this deformational process was repeated at intervals across what is now the general line of strike of these rocks the immediate effect would be to ease the stress, at least for a time, which was felt by the mass of rocks in which these ruptures occurred and to heap the rocks by piling some on others. Account must be taken of the possible former presence of other limestone strata beneath what is called "Chazy" and also of strata above what is called "Trenton" at the time of this postulated faulting. The rough regularity of the relations between the two strata, as now exposed, might be accounted for on the basis of certain primary structural relations which the mass of which they were a part had to the stress sustained by it.

Certain assumptions have clearly been made as the premises for the considerations just offered; but it will be remembered that effort was made to give a foundation of probability to the ages

of the rocks in the Brandon area which have been discussed by tracing the less altered rocks at the west into them through more or less continuous surface exposures and by careful lithological correlation and by general field relations.

The greater metamorphism of the rocks at the east in Brandon might be explained as due to several factors. These rocks might have been involved in primary, or at least antecedent, relations different from those at the west at the time they came under kinetic stresses; or they might have been subjected to continued or repeated compression after new conditions, such as a loading due to overthrusting, had been imposed; or they might be thought of as having been involved in the zone of most severe crushing in the region. These rocks at the east give evidence of having sustained pressure under confinement, whether this condition was a special one present only at the east when the rocks at the west were sheared into their present condition, or whether it was a condition antecedent or subsequent to the operation of those stresses which sheared the rocks at the west.

The deformational structure of the limestones west of Brandon, as far east at least as the present western margin of the "interbedded series," is that of shearing chiefly. This shearing seems to increase eastward towards the areas in which the rock has taken on the characters which are shown by the marble of the Otter Creek valley. It is practically along the meridian on which falls the present eroded western margin of the "interbedded series" west of Brandon village that the commercial marble runs out westward at the surface southwest of Brandon, and even the quarries, including the "old Goodell quarry," opened at this western limit south of the "Long Swamp road," one-fourth of a mile east of M. F. Phillip's house, were soon abandoned. One of these quarries shows very well the gray dolomite folded as a small patch with the dove-colored rock and both of these driven as one mass over the marble. The latter shows its bedded structure much more distinctly than does the more severely crushed rock farther east, which is a feature that falls in line with other characters to mark a transition zone between the rocks at the west and those of Otter Creek valley. South of the "Long Swamp road," between it and M. F. Phillip's place and about one-fourth of a mile southeast of Martin Ketcham's place, is a cliff in the limestone facing north. In the face of the cliff great irregular blocks of limestone rest against others along irregular contacts and where two come together, big chunks fall away, while the rock is broken throughout into small, irregularly shaped pieces, usually with good faces, but with much irregularity of shape, and the whole mass indicates beyond a doubt that it has been greatly crushed and brecciated, but apparently not under the same degree of confinement as the marble and other rocks farther east. The surface exposures roundabout, parti-

cularly to the southward, show intermingled dove-colored rock and its gray or chamois-colored associate, with occasional patches of marble. Each is deformed by shearing, a feature which the dolomite shows least, and all are much disturbed and involved with each other.

A number of considerations make it appear that there is a progressively increasing metamorphism from west to east in the calcareous rocks in passing from Sudbury into Brandon; but whether the relatively moderate shearing shown by the rocks at the west was a structure antecedent in the rocks at the east to the greater deformation now shown by them, or whether the two are different expressions of stresses acting at the same time but under different conditions is a question involving other considerations. In general it appears that all the various calcareous rocks which have just been described, were obliged to accommodate stresses by some molecular adjustment as well as by movement *en masse;* but accommodation by mashing and flowage differed at different places and was much more pronounced at the east, in those rocks which presumably are represented at the west by the blue limestones and their associated dolomites and dove-colored rocks.

On the assumption that these various calcareous rocks just mentioned are in general equivalent over wide areas and rest on essentially the same terrigenous formation throughout—an assumption that seems to the writer to have gained a considerable degree of probability—the thoughts arise as to how this relation came to be established and as to what is the age of the terrigenous rocks. Some of the latter have been called Ordovician and some of them Cambrian; but a field examination will show that it is hardly possible to separate them as belonging to different terranes on the basis of the lithological features of the rocks themselves, although certain types easily impress one as being of Cambrian age from a likeness to those which have been assumed with considerable positiveness to be Cambrian and the same might be claimed for other types with respect to their inclusion in the Ordovician. Whether we call them Cambrian or Ordovician, or both, the problem remains of accounting for the calcareous rocks above them, and the postulates which are formulated to explain the present relations will differ in the large for the different cases.

It was about at this point in the writer's studies that the need of certain more definite working hypotheses which could be further tested in the field appeared. Certain similarities in field relations insisted upon recognition; the terrigenous rocks, called for a more definite status concerning possible or impossible division and for a more definite assignment as to age; and the accumulated evidence for the action of powerful compressive stresses throughout a wide region and for clearly-defined thrust-

ing in certain parts of that region made it necessary to ponder as to the extent to which thrust movements were involved in the entire region's history.

The following are examples of some of the questions which came to mind:

1. Is there any evidence to show that the calcareous or the terrigenous rocks which have been described were first broken and heaped up by repeated reverse faulting and then carried westward as a mass over other rocks along a low-angle thrust plane so that they now rest by thrust unconformity on other rocks? In this connection what emphasis is to be put upon the apparent present contact surfaces of the calcareous rocks and the terrigenous formation on which they rest or the contact surfaces where the conditions are reversed and terrigenous rocks rest on limestone?

2. Is there any evidence to show that while the calcareous rocks have been disturbed in position their superjacent relation to the terrigenous formation was primarily due to normal marine overlap on a floor of eroded older rocks?

3. What explanation is to be offered for the apparent absence of middle and later Cambrian in the general region?

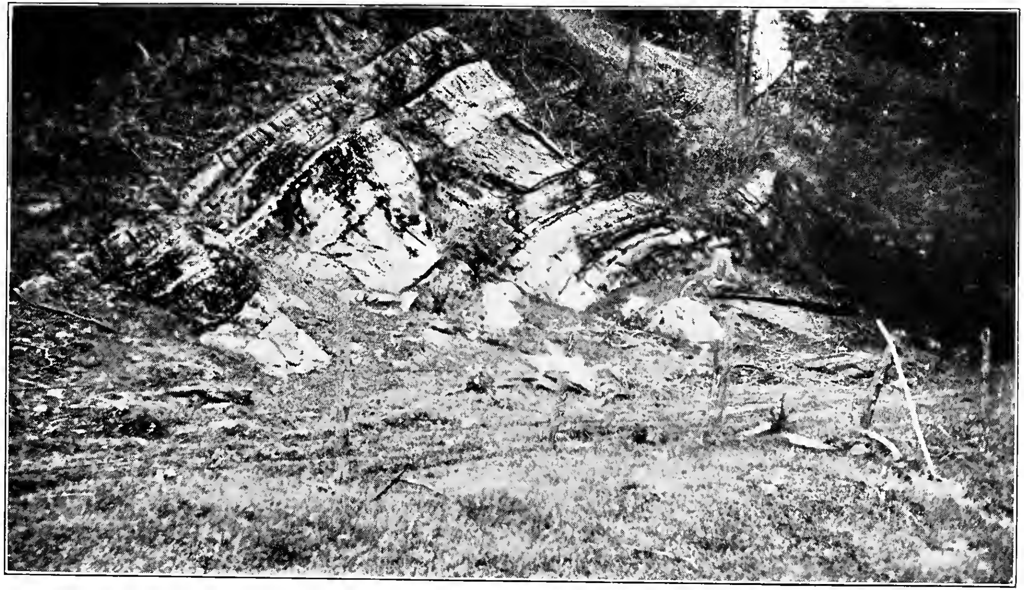
4. Is it likely that the Beekmantown as known near the lake is now present at depth or at the surface around Brandon and in the Vermont valley or the "slate belt"? Is it likely that it was ever deposited at the east and is there any evidence on this point?

These questions and others grew out of a study of the field relations in western Vermont and the possible answers to them are part of the problems of the region. They will have to be considered again.

The "interbedded series" of dolomitic limestones and quartzites in Brandon. This series is present in great force in Brandon township, north, east and south of Brandon village. In contrast with the marble and for the most part with the dove-colored rock and its associated gray or chamois-colored dolomite, the bedded structure of this series is well preserved in Brandon, in which feature it resembles other exposures of the series in the Vermont valley. The field relations at Brandon perhaps indicate its age less decisively than at other places, as at Bennington, for example; but the resemblance of the series to the entirely similar rocks at Bennington leaves no doubt of the similar age of the two and little doubt of the Lower Cambrian age of the series.

In the Bennington region a certain thickness of dolomitic limestone intervenes between the quartzite and the interbedded series. In Brandon neither the quartzite nor the dolomite are in the same simple relations to the interbedded series. In some places a dolomite is associated with the marble, as alluded to above, and this rock does not appear to have the characters of

PLATE XXX.



Interbedded dolomites and quartzites of probable Lower Cambrian age on the limb of a fold dipping westerly. These rocks lie a mile west of Forestdale village and near the west bank of Neshobe River. The photograph illustrates well the general appearance of the interbedded series in Brandon. The contrast with the marble of the region is made clear by comparing this plate with any of those showing the marble.

the striped rock that has been described or those of the gray rock associated with it. The dolomite referred to may be seen at most of the quarries around Brandon lying on or in the marble. It often separates the marble from overlying, interbedded dolomites and quartzites. As first studied by the writer it seemed to him to be a part of the Lower Cambrian series, but the field relations are much involved and not conclusive on this point. The probability of its inclusion with the Lower Cambrian would seem to depend to some extent upon the interpretation put upon the present structure of the rocks of which it is a part.

In a few places members of the interbedded series seem to lie directly on the marble. Such relation was noted in the field just west of the old Goodell quarry in Brandon along the old stage road to Leicester and Salisbury, where stringers of quartzite, irregularly disposed along the strike lie directly on marble. In places this quartzite thins out to nothing along the strike and at others widens out beyond any probable thickness of any of the quartzite beds of the series. These stringers look in fact like eroded remnants of members of the series which lay in a rather flattish position upon the marble. East of the road a few feet of dolomite lie on the marble in the old Goodell quarry and above it is the interbedded series again. A few rods west of the exposures showing the quartzite stringers is a ridge composed of the gray dolomite and the dove-colored limestone on which no recognized traces of the interbedded series is now present. Northwest of this ridge, across the road, are outcropping ledges of a band of marble which is succeeded westward by another ridge at the south end of which, in the open pasture just east of the back road to Morgan's Stock Farm, is an abraded anticline of what is interpreted as the interbedded series. The western limb descends across the back road to the plain of Otter Creek. Traced northward along the axis of the fold the interbedded rocks give place to the gray dolomites and associated dove-colored rock, but farther north on the northern side of a crossroad appear various eroded exposures of what appears to be the dolomite-quartzite interbedded series. The relations as thus described show the marble and its associated gray dolomite and limestone to be overlain by an eroded mass of the interbedded dolomites and quartzites northwest of Brandon village.

After an examination of the rocks in Orwell these relations were reviewed. While the interbedded rocks northwest of Brandon bear some resemblance to members of the Beekmantown west of Orwell village, they do not seem to be sufficiently like them to change the writer's earlier assignment of them to the Lower Cambrian. Moreover, they showed no traces of fossils. They have some differences at places from the interbedded rocks east of Brandon village, which seem, however, to be due to a shearing more nearly parallel to the bedding. Rocks like those

just described as probably Lower Cambrian also occur just north of the Rutland R. R. track, and two miles south an "island" in the plain of Otter Creek shows these rocks prominently exposed again on precisely the same meridian as those at the north, and farther south, still on the same meridian, northwest and west of the Seager farm, they outcrop again. They may thus be traced north and south through a distance of about three miles.

In places at the north, near the axis of the fold, there is pronounced shearing structure developed across the bedding, but at other places along the axis where the beds lie more nearly flat and along the slopes of the western limb of the fold, shearing seems to be more nearly with the bedding, producing thin, sheeted structure, and at many places these thin sheets are distinctly crinkled. Stringers and patches of salmon-yellow calcite mixed with quartz occur abundantly over the eroded exposures of these thinly-sheared beds.

Northeast, east and southeast of Brandon village, west of the road from Forestdale to Pittsford, the interbedded series is disposed in regular and irregular folds, often closely compressed, frequently overturned, and ruptured at many places along the strike, and probably also across it. A rupture along the strike may frequently be seen passing into a fold. Over these parts of the Brandon area the marble is wholly covered by these interbedded rocks, which are generally marked by higher altitude and greater thickness than elsewhere near Brandon.

Some of the ruptures in the series, just referred to, seem clearly to be reverse faults, which are best shown at those places where members of the series stand on edge, or are inclined at high angle with easterly dip, while contiguous members at the west dip at a moderate angle to the westward. One of these localities is a mile east of Brandon village, at Cheney corner. See section, figure 15.

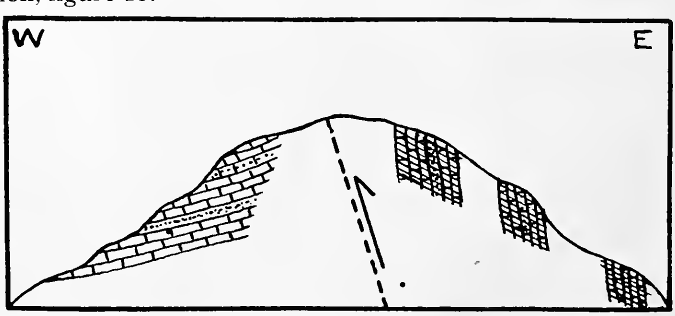


FIGURE 15. Structure shown by members of the interbedded dolomites and quartzites east of Brandon village, near Cheney corner; close folding and reverse faulting.

East of the Forestdale-Pittsford road. The interbedded series as described for the area east of Brandon village is suc-

ceeded on the east by terraced sand plains of old delta deposits and east of the Forestdale-Pittsford road by heavy bowlder drift which conceal outcrops. The heavy drift forms the lower western slopes of a series of high, ridge-like hills which begin in Forestdale and extend southward through Coxe Mountain in Pittsford. This range of hills is separated throughout most of its length from the steep, scarped slopes of the Green Mountain plateau by the valley of Sugar Hollow Brook.

The exposures in these hills from Forestdale southward present many features for comparison with the rocks forming the Sudbury and Orwell hills of the Taconic range. It is possible to identify some of the types in these foothills of the plateau with characteristic ones of the range. In the eastern hills there occurs a dolomitic limestone in association with the quartzite and phyllite which is now apparently wholly absent in the Taconic hills of southwestern Brandon, Sudbury and Orwell, except for some doubtful rocks on the eastern slope of Castle Mountain which have been mentioned.

Southeast of Forestdale are ledges of massive, brown quartzite which are separated at the present surface by a space of nearly a mile from the most eastern exposures of the interbedded series east of the village. Four miles to the south, however, the interbedded rocks are separated by only one-fourth of a mile from the drift slope of the range of quartzite hills. Southeast of Forestdale, back in the woods, is a considerable scarp and west of it, in the open fields just outside the village, is a succession of smaller scarps dropping off westward. West of the second of these dolomitic limestone apparently rests on the quartzite, but elsewhere in the vicinity the dolomite was not seen. Due north of these ledges, along their strike, on the road to Goshen, just east of Forestdale, are ledges of black phyllite and quartzitic schist entirely similar to those seen in Sudbury and Orwell and also at other places in this eastern range that will presently be mentioned.

Going southeast from Forestdale, ledges of quartzite are numerous at many places and it is possible to trace this rock through the woods and clearings along the low range of hills to Coxe Mountain. Exposures are chiefly found along the higher western slopes and summits. There are a number of significant associations which should be mentioned.

The hill road going east from the Forestdale-Pittsford road about two miles south of Forestdale crosses the summit of this range of hills and descends to Sugar Hollow. The summit point is known locally as "Birch Hill."

On the ridge north of Birch Hill, massive, brown quartzite forms the higher part of the western slope and is in contact with schist or phyllite which overlies the quartzite and extends eastward and northward along the ridge. The black phyllite or schist

forms large exposures, but is roughly intermingled on a large scale with quartzitic schist, or schistose quartzite, in which at places are large, chunky veins of quartz which have been opened by zealous seekers for gold. In one of the pits was noted a black, graphitic schist carrying pyrite and quite like that seen at places in Orwell. The dip of the rocks, which is probably cleavage structure in part, is easterly. The western slope of the ridge north of Birch Hill has scarps above the drift-covered portion and the eastern slope is abrupt and regarded as marking a fault displacement. No dolomite was found along the top of the ridge; but northeast of Churchill's house on Birch Hill, on the eastern slope, are small patches of dolomite, apparently in place. South of Churchill's house, across the road, an east-west section gives massive quartzite at the west, then eastward quartzitic schist with a small patch of dolomite.

South of Churchill's house and west of the Sugar Hollow road, patches of dolomitic limestone occur sparingly as remnants of erosion on the eastern slope of the ridge. At places also the same association of quartzitic schist and phyllite with massive quartzite noted at the north occurs along the southern extension of the ridge. East of an old road which joins the Sugar Hollow road with the Birch Hill road, on the east side of a gulley, is quartzitic schist carrying pyrite and overlain by dolomite, while west of the gulley are big ledges of massive brown and granular quartzite which continue on the strike to join the exposures north of the Birch Hill road.

South of Churchill's corner the Sugar Hollow road descends for a mile over a gentle slope nearly to the brook. The old road over the ridge passes through a sort of col which may mark a structural sag, for directly south of the point where the old road joins the Hollow road the quartzite gave a reading of N. 72° E. and a dip of 36° N., which is a marked deviation from the prevailing north-south strike of the rocks. Directly north of the place giving this anomalous reading, dolomite rests on the quartzitic rock and its presence here leads to a suspicion that the low pass just north may be due to erosion of dolomite lying in an irregular sag.

Just south of the point where the old road joins the Hollow road a scarp appears west of the Hollow road and continues southward.

Two miles south of Churchill's corner a small basin in the hills holds Sugar Hollow Pond. The basin is a faulted one. Scarps bound it on the east, northeast and probably on the south. East of the pond is a succession of low ridges broken by strike faults which are marked by westward-facing scarps and intervening swampy gullies.

The terrigenous rocks composing these hills of the ridge or range just described present many similarities to those west of

Brandon in Sudbury, both in their lithology and structure. They are evidently broken by numerous faults as well. Massive quartzite is more abundant at the east and a dolomite is present at places, but otherwise the student will be impressed by the very strong similarities, amounting to identities so far as distinguishing among them is concerned.

It has been suggested above that the terrigenous rocks of Sudbury pass beneath the marbles of the Otter Creek valley to join others at the east. This should be construed as only a general statement; no implication was intended that the terrigenous rocks at the east may not have been greatly disturbed in position.

East of Sugar Hollow Brook. East of the brook the topography is marked by sheer precipices, steep slopes and a rugged surface generally. Displacements by faulting are very evident. The western scarps which were cleared by glacial action were too high and extensive to be banked and covered with drift and now offer a somewhat imposing view when observed nearby.

In common with other portions of the western edge of the plateau the total displacement now apparent between general upthrow and downthrow areas has often been effected along several distinct planes. Along what appears as a single plane the amount of displacement will vary at different places along the strike. A scarp will often pass into a monoclinal fold and at some indefinite distance across the strike will be replaced by another scarp which will perhaps overlap the former along the strike and perhaps also another which has in its turn replaced the second. This arrangement impresses the observer of the topography east of Sugar Hollow Brook.

From the junction of its head streams the brook flows at the base of a prominent scarp on the west of the Chaffee Mountain mass. The considerable height of the scarp may be seen very clearly where a recent slide has cleared it of trees and other vegetation. This scarp is replaced eastward by another higher precipice at whose summit is a shelf that on a clear day gives one of the finest views in the Vermont valley.

Chaffee is best ascended along its northern slope from the valley of the eastern tributary of Sugar Hollow Brook. Massive quartzite forms the bed of this tributary and its valley and the ascent of Chaffee is over similar quartzite, dipping easterly, which can be followed to the shelf above mentioned and from the latter place to the summit where the easterly dip still prevails.

The ascent of Chaffee was made by the writer under trying conditions; the summit was enveloped in clouds and the rain came down in torrents. The atmospheric conditions caused some bewilderment so that observations could not be made with the desired accuracy in the thick woods of the mountain. About a mile as estimated, south-southeast of the summit of Chaffee

Mountain, along the upper portions and summit of an eastward slope is dolomitic limestone, which here from the field relations apparently lies on the quartzite. A sort of col here permits an easy descent on the west side which is made over dolomite and quartzite by zigzagging down slope among a number of small scarps to the valley of Sugar Hollow Brook.

On a subsequent trip along the western slope of the "Moonshine"-Nickwaket range, along an old wood road that ascends to the col mentioned above, black phyllite was found in a scarp overlain by massive quartzite which was succeeded up the slope by exposures of dolomite. There is a small settlement on the mountain side above the contour of the scarp and at the base of Nickwaket and in the cleared fields of these farms the dolomite is extensively exposed. On the east side of a road through the settlement, near its northern termination, the dolomite dips eastward at a moderate angle, but farther east up the slope the dip is westward at a high angle.

A half mile southwest, west of this back road, the surface rock shows undulating not much compressed interbedded dolomitic and quartzitic layers which resemble the interbedded series. These are bordered by a scarp on the west, at whose base is a black, sheared quartzitic schist, which southward passes into massive quartzite. Then westward the dolomite again forms the surface rock which farther south on the slope and in the valley of the brook can be seen grading downward into quartzite and arkose, all dipping easterly at a moderate angle. West of these outcrops is Sugar Hollow road and then the quartzite of Coxe Mountain.

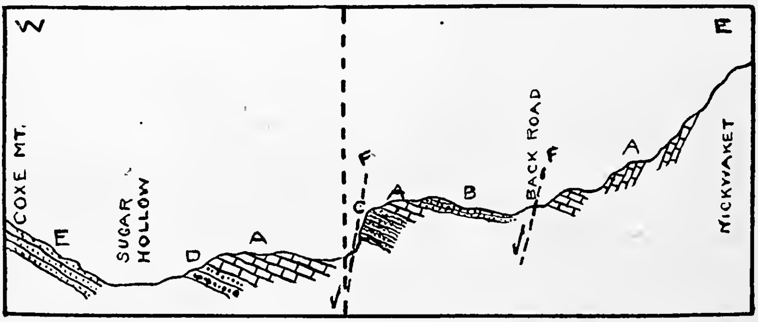
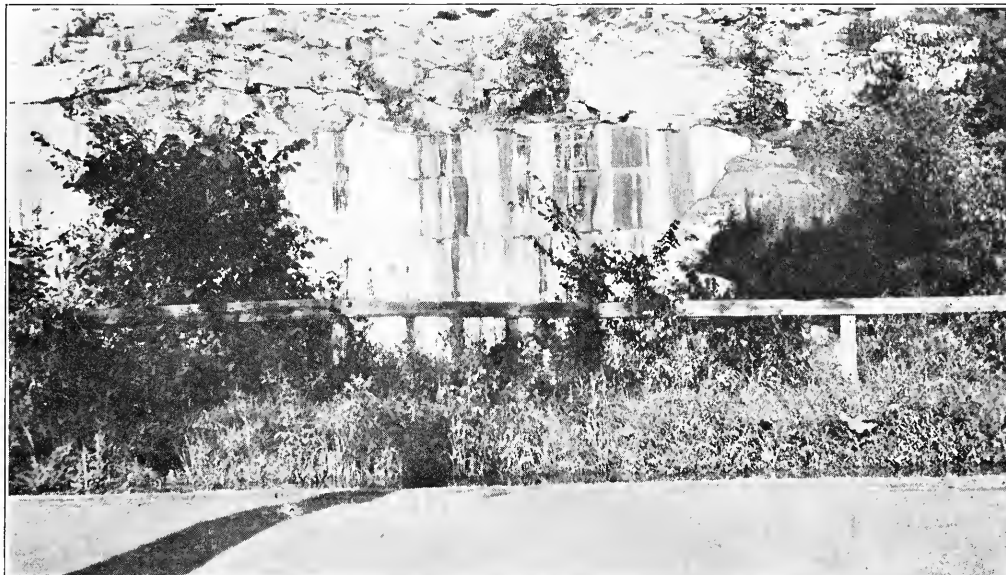


FIGURE 16. A generalized surface section of the margin of the Green Mountain plateau southeast of Brandon village, from Nickwaket Mt. westward through Coxe Mt. with offsets along the strike. Principal offset shown by dotted line. A, dolomite; B, "interbedded quartzites and dolomites"; C, quartzitic schist; D, quartzite and arkose; E, quartzite; F, probable faults.

The observer passing northward along the Sugar Hollow road, from the point where the back road referred to above joins the Hollow road, would hardly fail to notice the conspicuous

PLATE XXXI.



Contact of dolomite and marble in the old Goodell quarry at Brandon village. A common association in the quarries near Brandon.

ledges of dolomite on the east side of the road and would hardly fail to see that the beds are always folded and sometimes overturned to the west. Throughout the same distance on the west side of the road the quartzite of the ridge extending northward from Coxe Mountain is broken by a scarp on the east. Some dolomite occurs on the west side of the road. The scarp ends at the north at the place where the anomalous strike in the quartzite was noted. East of the road at this point dolomite dips at a gentle angle easterly, but on the west side of the road it shows much confusion.

East of Sugar Hollow Brook then are found:

1. Massive quartzite forming the prominent scarps;
2. Dolomitic limestone at places on the summits and in large exposures on the western slope of this mountainous strip, apparently resting on quartzite;
3. Black phyllite and quartzitic schist in scarps overlain by massive quartzite;
4. Apparently some representatives of the interbedded series, whose relations are not clear, but which presumably rest on the dolomite.

This whole series has clearly undergone much disturbance, in fact more than one deformation, but it seems reasonably clear that the rocks all belong to one series and that they are of Lower Cambrian age by analogy with other rocks having similar characters and relations in other parts of the Vermont valley. The original depositional sequence is not clear from the interrelations shown east of Brandon. From the relations at Bennington we have:

1. Massive quartzite, at the base;
2. Dolomitic limestone;
3. Interbedded series.

The relation of the schist is not wholly clear. It seemed to be a part of the basal quartzite formation and interstratified with it. In explaining the present field relations, account must be taken of erosion as well as deformation.

General structural relations of the interbedded series and the rocks of the plateau east of Brandon. The interbedded series just east of Brandon clearly shows within itself deformational features of several kinds, most of which are due to compression and some of which are the result of normal faulting. The effects of compression may be summarized as follows: (a) buckling, with frequent formation of tightly compressed folds, which are often overturned; (b) shearing across the bedding of the folds; (c) reverse faulting along the strike, which is indicated clearly at several places.

The field relations which the interbedded series has to the other strata with which it is now associated around Brandon village, in the writer's opinion, could leave little doubt, after a

careful field inspection, that the former is superjacent to the marble and the dove-colored limestone and its gray dolomite associate. The interbedded series has been worn through over many large and small areas, with the consequent exposure of the other rocks on which it lay. The more or less detached exposures of the interbedded rocks along its western portion west of Brandon are inliers of this formation on presumably younger rocks, or are in process of becoming such. This relation makes the marbles and their associated rocks outlying belts in an older series. The number of contacts and outcrops that reveal this relation is manifestly reduced by concealment under drift or by difficulty of correlation of certain dolomites lying on the marble. There may also have been some deformation of all these various rocks, including their plane of contact, subsequent to that which superposed the older series on the younger strata. The evidence may be summarized as follows:

1. The contrast in metamorphism and deformational features which the two formations show when in proximity;
2. Ragged erosional remnants of the resistant quartzitic members of the interbedded series on the marble and its associated rocks at various places;
3. The interrupted outcroppings in bands of the marble through the interbedded series and a probably related dolomite.

From the east-west width of the area in which the marble outcrops through the interbedded formation we may infer with some reason that the marble underlies the interbedded rocks east of Brandon; but how much farther east the marble extends at depth is a question whose answer would depend a good deal on the interpretation given to the relations of the rocks of the plateau to those of the valley.

There is little hint of what lies at depth beneath the sand plains and drift that occupy the space of varying width along the Forestdale-Pittsford road between the interbedded series and the range of quartzite hills east of the road. Farther north, east of Lake Dunmore, a prominent scarp marks a normal fault and this scarp falls precisely along the line of the projection of the Forestdale-Pittsford road northward. The great pile of drift that extends along the western slope of the ridge south of Forestdale suggests that a cliff has afforded a convenient place in which to pile this débris. The slighter development of drift at the north around Dunmore, in contrast with conditions east of Brandon, is quite in consonance with the variability in this respect shown by other portions of the Vermont valley. It is close to the line of this assumed displacement east of Brandon that the kaolin mine at Forestdale with its deposits of lignite and limonite occurs.

Prominent scarps bound the interbedded series on the east, southeast of Brandon village, west of the Pittsford road. Their significance is not clear. They suggest displacements. Pre-

glacial and base-levelling forces and glacial plucking, evidently availed themselves of a general line of crustal weakness along the region of the intervening surface space just described. The map brings the interbedded series and quartzite in contiguity; but the implication is general rather than precise, for there are indications at Forestdale that schist or phyllite lies beneath quartzite and it is not unreasonable to think that the presence of more friable schist, interbedded with the quartzite, might have been the primary contributing cause of the space that has been mentioned.

The quartzite of the ridge south of Forestdale, which is overlain and possibly underlain by phyllite and therefore interbedded with it, joins at the present surface with the quartzite of the higher plateau slopes east of Forestdale which affords some reason for regarding them of the same age and therefore for regarding the terrigenous rocks of the Orwell and Sudbury hills as in part of the same age as the plateau rocks. But it seems that too much reliability should not be placed upon the present surface continuity alone, here or elsewhere in the Vermont valley, in view of unquestionable deformation of more than one kind and the probability of lateral as well as vertical displacement of the rocks now forming the edge of the plateau.

It is not easy to fix the precise relation of the schist in the ridge south of Forestdale to the associated quartzite by reference to these rocks alone. It appears to be conformable. It is even harder to be satisfied of the relation which the patches of dolomite along this ridge have to the schist and quartzite. It seems rather likely that the formation which forms the probable basal member of this series of quartzite and phyllites, dolomites, etc., as a depositional mass varied originally in composition, both laterally and vertically, not only as a result of overlap, but from other causes as well and that a vast mass of sands and muds of different kinds was finally spread over the sea floor.

In general it would appear that the quartzite-phyllite formation is basal to the dolomite and that the former has been elevated against the interbedded series by reverse faulting and that a lateral thrust has carried the latter over the marble and its associated rocks at the west. It does not seem possible to account for the present superposition of the interbedded series on the marble and its associated rocks on any other basis, if the conclusions regarding the relative ages of these formations are in general correct. Apparently the lateral thrust drove for some distance above the schist and through the dolomite, for the schist appears nowhere in the Brandon region between the marble and the interbedded series, although it is entirely possible that the marble extends at depth beneath the quartzite-schist ridge east of the Forestdale-Pittsford road.

It seems reasonably clear that the interbedded series and the quartzite-phyllite formation belong to one terrane from the rela-

tions which they have to each other throughout the Vermont valley. If the interbedded series has been thrust on younger rocks we may reasonably infer that probably the quartzite has also. The field relations of the interbedded series give the clue to the meaning of the position of the quartzite and schist east of it; the latter have been brought up by reverse faulting as the result of rupture following compression and probably a low angle thrust plane cuts the reverse fault plane somewhere at depth. It is not so apparent whether the quartzite with its overlying dolomite east of Sugar Hollow Brook, which now form the rugged edge of the plateau, are separated by a reverse fault from the quartzite-phyllite west of the brook, because normal faulting obscures the relations between the two; but while the peculiar pattern of these normal displacements, in which the faults pass at the present surface into folds, suggests that except for normal faulting these various terrigenous rocks east of the interbedded series are not broken except by tension faults within the area of the map, conditions at other places may lead to another conclusion.

Approaching the question of the correlation of the terrigenous rocks on the west and east of Sugar Hollow Brook from the viewpoint of their general associations, their similarity in age and common membership in the basal formation gains considerable increase in probability, in the writer's opinion. So far as the writer's observations go there is no reason to suppose that the quartzite of Chaffee Mountain, "Moonshine" and Nickwaket, and certain quartzites and arkoses in the valley of Sugar Hollow Brook are any older than the quartzites and phyllites of the ridge of hills west of the brook. The rocks west of the brook are dismembered portions of the plateau, dropped down by faulting, in the formation of a great downthrow region. In this downthrown mass the interbedded series, of course, also belong.

How far east the marble may extend beneath the rocks of the plateau is a question whose answer rests wholly upon the answer to the prior question of how far does the thrust plane, whose existence seems to be established by the present relations of the interbedded series, extend east of the present western edge of the plateau. If the thrust arose in a reverse fault near the present margin, then presumably on the basis of the relations which the marble seems to have to these terrigenous rocks and the equivalence of the latter to each other, the marble would not be found at depth east of such a root fault. The thrust plane cannot be traced eastward beyond the exposures of the marble and its associated rocks from beneath the interbedded series because its trace must be made from the surface. There does not appear to be visible at the present surface any transection of the plane. Reconnaissance trips by the writer in the plateau have failed thus far to give anything that could be construed as

the root of a great thrust. Its eastward extension is wholly problematical.

It was suggested above that probably a lateral thrust in carrying the interbedded rocks over on the marble had sheared above the basal formation into the calcareous members of the Lower Cambrian rocks. An important principle seems to be involved here. Probably we are inclined to look for too much regularity in the manner in which a great lateral thrust would drive through a mass of rocks. Because the thrust has apparently cut in a certain way through the rocks now near Brandon is no positive indication that the shear would have been just like it at other places, while the general fact of an elevation of Lower Cambrian rocks and overthrusting by them would still hold for many places. In other words, we might expect that in some cases the plane of thrust would have been such as to carry the terrigenous rocks of the east over on the marble and its associated rocks. The recognition of such a possibility in the presence of evidence for general overthrusting might greatly affect the interpretation of relations at many places and such possibility will be called to mind in dealing with certain relations farther south in the Vermont valley.

In considering the ideas and possibilities which have just been discussed, the question continually arises in one's mind as to what extent these various rocks were covered by others at the time of overthrusting. Did the overriding Cambrian carry with it a heavy load of younger rocks? Certain other questions arise: Did the marbles which are now found west of the plateau once extend over it to the eastward? Is there more than one thrust plane, one by which the marble and its apparent counterparts at the west, together with their associated rocks, were heaped up and carried westward and another along which the Lower Cambrian rocks broke through the marbles and overrode them? Did the latter rupture occur first and so bring an extra load on the calcareous rocks now represented by the marble and thus cause their greater metamorphism? Were the marbles and their counterparts ever covered with other rocks, especially with terrigenous rocks? They have been assumed to have been and the marble has been assumed to have been thrust through the younger terrigenous rocks or exposed on anticlinal folds through them. Why do not terrigenous rocks appear between the marbles and the interbedded series around Brandon, not by overthrust of lower members of the Cambrian, but because the marbles were overlain by terrigenous rocks? Is it because these were eroded before the thrust of the Lower Cambrian? Was the thrust which we now see evidence of around Brandon an erosion thrust, that is, one consequent upon previous erosion of the various rocks? If the terrigenous rocks that are found at places lying above the marble and which have been described as Ordovician

are such, why do not similar rocks appear above the less metamorphosed Chazy-Trenton rocks that have been described by the writer on previous pages? Why are such rocks absent north of the Taconic range in Leicester, Salisbury, Shoreham and neighboring towns? Must we discount or discard the ideas that the various calcareous rocks, which were described as lying on a terrigenous foundation common to all, are actually in such relation and essentially equivalent? Again in this connection what significance has the similarity of the terrigenous rocks east of Brandon to those of the Sudbury and Orwell hills? If some of the latter are of different general age than others, why does not some pronounced structural arrangement appear among them so that they may be separated? If it should prove more than probable that rocks carrying fossils in Sudbury have been crushed into marble in Brandon does it appear probable that difference in degree of metamorphism among the terrigenous rocks is any sure criterion of difference in age? Is there anything in the lithology of the various terrigenous rocks that is positive enough to separate them into different terranes? Has account been taken of possible overthrust bringing schists into contiguity with less metamorphosed terrigenous rocks; or of an overthrust margin separating rocks of one age from those of another on each side of it, except possibly where rocks which have been overridden now appear through the overthrust mass on account of erosion? In a region of thrust displacements, how much value can be assigned to apparent surface transition? What relations have the overthrust phenomena along the lake to those at the east? Are there field relations anywhere in western Vermont that show the Ordovician rocks resting or probably resting on Lower Cambrian strata?

Allusion has been made to the presence of a great downthrow region bordering the Green Mountain plateau for a long distance on the west. In the writer's judgment recognition of the reality of this great structural feature is all-important and it seems to him that failure truly to appreciate the extent of the region and the significance of the principle involved has been an element of confusion in his own thinking and that of others.

At the present time the Green Mountain plateau structurally appears to stand as a great upthrow block of the crust with reference to certain rocks that lie to the west of it. This relation holds irrespective of whether the plateau has been thrust up or the other area has sunk; but enough has probably been said already to show that it is the writer's idea that this present manifest relation of upthrow and downthrow regions was produced by a deformation quite separate from any of the great overthrusts which have been described. It is necessary to appreciate that the genesis of this relation is of much more ancient date than any purely physiographic relations that now obtain between the

two, and that although crustal warping and other disturbances may have caused minor movements and changes in their relations, in a primary and larger sense the present general relation of upthrow and downthrow areas probably antedates the destruction by erosion of a loftier region, although one cannot be so positive about how long after the great thrust movements of the general region the relation of upthrow to downthrow by normal faulting was produced, because the date of the thrusts is so uncertain.

The part of Vermont lying west of the Green Mountain plateau includes the other physiographic divisions described in a preceding section of this paper. From consideration of the ways in which rock deformation is known to have occurred it will appear that there are several purely theoretical possibilities as to the relations which the rocks of these divisions might hold to one another.

1. The Taconic range, Vermont valley and Champlain lowland might all be interpreted as parts of a general downfolded region with respect to the Green Mountain plateau and as owing their present physiographic contrasts entirely to differential erosion of a region of relatively simple folds, in which region the rocks west of the plateau constituted a compound, structural synclinorium and those of the plateau the complemental anticlinorium. Faulting and particularly thrusting played only minor parts at any time in the history of the region. In connection with this view the rocks at the west might be considered as originally members of a great geosynclinal of deposition, while those of the plateau belonged largely to a contemporaneous positive segment of the crust. Sedimentation might have been interrupted without changing the essential relations of these two regions, but eventually produced a great thickness of rocks which were later compressed without being profoundly displaced with respect to one another.

2. The rocks lying west of the plateau might all be regarded as parts of a great downfolded region without having suffered much deformation by thrusting, as postulated under 1. At some subsequent time great trough faults were formed producing the structural outlines of what are now the Vermont valley and Champlain lowland, which stand as downthrow regions with respect to both the plateau and the Taconic range. The present physiographic relations are thus primarily structural in their genesis and secondarily due to erosion. The rocks of the Taconic range and the plateau have the same general relations to each other that they had originally and prior to normal faulting, except for folding.

3. On the basis of known overlap at certain places in western Vermont of older on younger strata the rocks at many other places within the region might be considered as now remote from

their original places of deposition as the result of deformation of the crust by great thrust movements carrying the masses of one segment of the crust over on those of another for considerable but indeterminate distances, with or without much folding, thus bringing into juxtaposition rocks of widely different ages. At some time subsequent to such deformation by thrusting, normal faulting occurred and produced the structural outlines of the Vermont valley and Champlain lowland. These faults literally chopped these overthrust masses along many planes and introduced a confusion calculated to baffle any attempt to explain the present structural relations. If in addition to these deformations there were others, such as folding of irregular thrust planes and repeated normal faulting a very tangled aspect would undoubtedly be produced. Normal faulting in laterally thrusted masses conceivably might give relations that would have strong resemblance to such as would be produced by reverse faulting.

RUTLAND COUNTY.

Townships of Danby, Mount Tabor, Wallingford, Tinmouth, Clarendon, Rutland, Proctor and Pittsford.

(Pawlet, Wallingford, Castleton and Rutland topographic sheets.)

Topography. The areas which will be described in the townships mentioned in the heading for the most part lie in the Vermont valley in its extension north of Dorset Mountain. The rocks along the edge of the Green Mountain plateau at the east and a few in the Taconic range will be briefly mentioned.

The Vermont valley north of Dorset Mountain is marked by a ridge which extends northward from Danby to Rutland. The place of this ridge is then taken by two shorter ones; one of these separates the valley north of Center Rutland from that at West Rutland and the other forms Pine Hill northwest of Rutland.

Otter Creek enters Danby from Dorset at the south and flows in a valley between the edge of the plateau and the ridge that runs north from Danby; but at Rutland the stream turns westward to Center Rutland and flows in the Center Rutland valley west of Pine Hill as far as Proctor, where it enters the wide valley in Pittsford.

By the ridges mentioned the main valley is thus broken into several minor ones which have been excavated in softer rocks than those which compose the ridges. The surface topography of this portion of the Vermont valley therefore differs from that south of Dorset Mountain, but the main outlines of the valley between the plateau and the Taconic range are maintained throughout, except for the interruption by the Dorset Mountain mass.

PLATE XXXII.

A photograph looking northeasterly across the Vermont valley from the lower portion of the northeastern slope of Danby Hill, showing a terraced modified drift or delta plain in the foreground and a characteristic view of the marginal portion of the Green Mountain plateau in the distance.

General note. North of Dorset Mountain the Vermont valley in its extent from Danby to Pittsford, including the detached ridges that have been mentioned in the brief discussion of the topography, presents a great number of most remarkable and illuminating field relations that can be truly appreciated only after an examination of them. An adequate discussion of the geology of this part of the valley would speedily pass beyond the limits of a general paper like the present one. All that can be done is to give what appears to be essential. Outside the Bennington and Brandon areas the writer spent more time in this than in any other part of the valley and devoted parts of five days to a careful inspection of the region.

General description. North of Dorset Mountain lies Danby Hill which, as will be discussed, is separated by an east-west fault at the south from the mass of Dorset Mountain and which northward joins the ridge which extends through Tinmouth, Wallingford and Clarendon to Rutland.

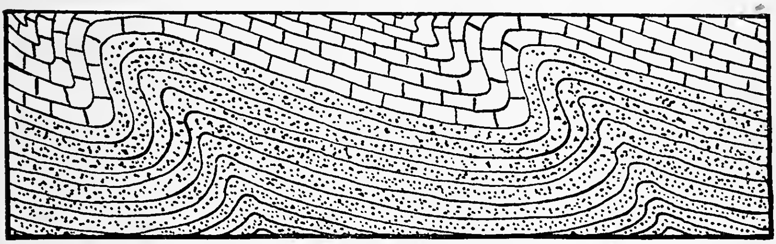


FIGURE 17. Composite drawing designed to show structure of quartzite at the foot of the plateau between Danby and South Wallingford and that along eastern slope of the Danby-Clarendon intermediate ridge; also that of the overlying dolomite. The overturning is westward.

On the east, Danby Hill slopes rather gradually to the plain of Otter Creek. North of Danby Hill the eastern slope of the ridge is often much sharper and sometimes, near the base, abrupt.

Danby Borough is on the eastern edge of Danby township. Danby station is in the adjoining township of Mount Tabor. A mile and a fourth east of the station begins the steep slope of the plateau which is cut east of Danby by the gorge of the "Big Branch." In the bed of this stream at Mount Tabor village the compact, massive quartzite outcrops. Thence it may be followed in the valley northward to large ledges along the railroad track three miles north of Danby station. The boundary of the quartzite then bends easterly away from the track at South Wallingford and its place is taken here along the meridian of the ledges farther south by members of the interbedded series and by limited outcrops of marble. The ledges of quartzite along the track are only a little over a mile, if that, east of quartzite-phyllite outcrops on the northeastern slope of Danby Hill. Except for difference of present altitude of Danby Hill and the erosion of its eastern slope, the relations of plateau, narrow valley, and western ridge

at some places in Danby is like that farther south, east of Dorset Mountain.

The structure in the quartzite of the ledges along the track, just referred to, is generalized in the accompanying sketch. See figure 17. A mile west of these ledges, on the west side of the creek at a sharp turn in the main road, dolomite shows the same structure. We see the quartzite and the superjacent calcareous beds buckling under compression to form overturned folds.

The marble outcrops on the northeastern and northern flanks of Dorset Mountain give place northward under drift to quartzite and to members of the interbedded series of the Lower Cambrian in Danby Borough and along the eastern slopes of Danby Hill. In the bed and banks of Mill Brook in Danby Borough, beds of dolomite have a flattish position with very gentle arching, slight easterly dip and apparently a slight southerly pitch. A mile and one-fourth southwest of these outcrops along the brook road from Danby Borough to Danby Four Corners, at the bend in the road, what appear to be dolomitic members of the interbedded series have been folded into a small anticline and overturned so as now to form an acute, recumbent fold. East and west of the dolomite is quartzite. Along the meridian of these outcrops about one and a half miles north of them on the eastern slope of Danby Hill the interbedded members of the Lower Cambrian series outcrop and here apparently mark the eroded edge of a more extensive covering of these rocks. On Danby Hill they extend eastward to join those in the valley of Otter Creek. Further discussion of them may be given after following the section as begun along the brook road and after noting certain other exposures lying north and south of the road.

Westward along the brook road the outcrops of quartzite west of the recumbent dolomite give place to a black schist, well exposed in the bank at the second fork in the road and which continues northward over the top of the hill along the same meridian and joins the schist exposures along the higher eastern slopes of Danby Hill. West of the schist outcrops in the bank of the road in both of the high walls of the gorge of the brook is somewhat massive quartzite. This quartzite was not carefully traced northward at the surface, but on the meridian of this quartzite in the gorge of the brook, on the southern slope of Danby Hills, occurs the black schist or phyllite, and the latter occurs westward along the road to Danby Four Corners. Southward towards Dorset Mountain along a back road are fine exposures of massive, brown quartzite which are surrounded by drift and whose actual extension could not be followed. A mile west of these outcrops the bed of Mill Brook, which flows eastward, is strewn with quartzite boulders. Hosts of big quartzite boulders fill the drift south of Danby Hill, which is a feature doubtless associated with the action of the ice in stripping the

slopes and summit of the hill and parts of the ridge at the north.

One-third of a mile south of Danby Four Corners and east of the hamlet on the southwestern slopes and northward along the lower western slopes of Danby Hill is a bluish-gray or bluish limestone, weathering gray and appearing in many outcrops. Fossils were not found in this rock by the writer, but they have been reported by Foerste,[1] and regarded by him as having a Trenton aspect. A mile and a half north of the Corners a crystalline limestone shows a brecciated condition on the gray, weathered surface, but is quite healed and without obvious fragmentation on the fresh surface, which is of dark blue color. From the writer's acquaintance with other areas this blue rock would have been tentatively correlated with Trenton and certainly not with the Cambrian.

Above the blue limestone outcrops at the base of Danby Hill, along the path up the hill traversed by the writer, outcrops are lacking until about half way up when black phyllite or schist appears which continues over the summit and outcrops at intervals therefrom down to about the 1,100 feet contour, when the topography changes somewhat in passing from the schist to some outcrops of sheared, bluish marble standing on end and then a short distance eastward appears the characteristic association of the interbedded series of the Cambrian, which is traceable south by west as the eroded edge of the Lower Cambrian series along the slope of Danby Hill alluded to above. Some conspicuous ledges of massive quartzite also standing on end appear just west of the margin of the interbedded rocks. The surface succession is thus within a fourth of a mile or less across the strike from west to east, with slight offsets to include outcrops: 1, schist; 2, sheared, blue marble; 3, massive quartzite; 4, interbedded series.

A half mile north of the exposures just described the schist outcrops east of the marble. There is, in fact, at this place a confusing intermingling at the present surface of marble, schist and quartzite.

North of these ledges, bearing to the west across Baker Brook, the schist or phyllite forms most of the surface outcrops, with occasional patches of limestone or marble, to the summit of Clark Mountain. Here on the summit and western slopes massive, heavy quartzite forms a continuous outcrop over large areas with the phyllite or schist lying to the east. Thick quartzite dipping about 30° westerly was traced for a mile along an old lumber railroad at the summit of the western slope. The western surface slope of the mountain is fairly steep and bevels across the westerly dipping quartzite. Across the road at the western base of the mountain the interbedded members of the Cambrian were noted dipping 66° westerly along a strike of N. 19° E.

[1] Amer. Jour. Sci., 1893, vol. 46, pp. 435-444.

West of Danby Hill and Clark Mountain is the Tinmouth valley, much of which is low, swampy land. It joins at the north with the valley of Clarendon River.

At the southern end of the Tinmouth valley, one mile west of Danby Four Corners, black phyllite or schist outcrops along the road to Tinmouth for a mile and a half north of the Pawlet road. Between the schist and Danby Pond there appears to be some "marbly" limestone. About two miles southwest of Danby Four Corners is blue limestone. The phyllite is precisely like that which occurs in the ridge at the east and in the various localities described on previous pages.

Three miles north of the road from the Corners to Pawlet, and 75 rods west of the Tinmouth road, and along the same general contours northward are exposures of strongly-sheared limestone or marble. At many places these ledges of marble do not at all appear like the outcropping edges of thick masses of the rock, but rather as a broken covering to some rock on which it lies. Two miles west of the Tinmouth road, within the main range, at the southern end of Harrington Hill, is what appears to be an isolated patch of marbly rock lying on the terrigenous formation. On the trip which was made to inspect these relations there was not time to map the country with the care necessary to show the extent to which the marble or its probable equivalent occurs in scattered exposures over the hills, or to ascertain to just what extent it is interrupted at the surface by the phyllite along the western edge of the Tinmouth valley. It was hoped that there would be another opportunity to investigate the relations within the hills at the west. There are indications of considerable massive quartzite on the west side of the Tinmouth valley in the general vicinity of Tinmouth.

On the eastern slope of Clark Mountain are patches of bluish limestone not so severely metamorphosed as the marbles of the region usually are. They appear to rest on the schist. In the valley of Otter Creek on the west side of the stream at South Wallingford are exposures of the heavy marble, including a quarry. Adjacent to these and extending eastward from them are the interbedded rocks of the Lower Cambrian, and east of these, less than a mile away, is the quartzite of the plateau.

The interbedded members of the Lower Cambrian continue northward from South Wallingford on the east side of Otter Creek, forming conspicuous hills two miles north of the village. In these the beds have been compressed so that they now stand on end. Northward between these exposures and the village of Wallingford the quartzite of Green Hill comes down close to the railroad track with a low but good scarp on the west.

Westward across the creek and its flat flood plain, near Wallingford village, three-fourths of a mile away, is a sharp ascent from the level of the plain which the writer at the time of in-

spection put down as a probable fault. It runs along the eastern base of the ridge that extends northward from the Clark Mountain portion for 4 or 5 miles. The rock along this slope is schist or phyllite; but northward, southwest of Clarendon village, the place of the sharp slope is taken by a more gentle one and that of the phyllite by quartzite. The base of the sharp slope referred to is marked by swampy land for part of its extent and southwest of Wallingford by Fox Pond.

Westward from Wallingford village over the ridge the surface rock is largely schist or phyllite, with some quartzite. The boundaries of these two rocks were not traced along the ridge for 4 miles north of the road that crosses the ridge from Wallingford village to Tinmouth village, except on the west slope where the road descends diagonally across massive quartzite.

Clarendon village in the Otter Creek valley is 4 miles north of Wallingford village. West of the former the eastern slope of the ridge that lies to the west rises rapidly but gradually from the level of the creek over quartzite which shows the structure given in figure 17. About 300 or 400 yards up the slope from the main road, members of the interbedded series of the Cambrian apparently lie on the quartzite as they do on the eastern slope of Danby Hill. The prevailing surface rock over the ridge to Chippenhook is quartzite; but on the west slope east of Chippenhook appears the interbedded series which continues westward into the valley of Clarendon River. At Chippenhook, in the valley and east bank of Clarendon River, the beds of the interbedded series stand at a higher angle than farther east. A similar relation was noted between the quartzite of Clark Mountain and the interbedded series lying west of it. It appears that these rocks, both in their larger and smaller folds, show overturning westward.

Southeast of Clarendon Springs, east of the road that ascends from Chippenhook over Boardman Hill, black schist or phyllite ledges are intermingled with others of gneissic-looking quartzite, and the two are often together and in contact in the same ledge. Northward down the hill to the bed of a brook is massive, thick-bedded, jointed quartzite, dipping easterly at a low angle. Eastward along a road that follows the brook to Otter Creek is quartzite dipping easterly and apparently extending to the eastern base of the ridge. The rock is often gneissic at the east.

East of Clarendon Springs at Flat Rock and northward, east of the road over Boardman Hill to Center Rutland, is quartzite, often gneissic in appearance, having essentially the same relations to schist or phyllite as noted above, but with the resistant ledges of the quartzite often forming knolls of higher elevation than the adjacent schist and giving a strong impression of quartzite pushed over on schist.

The road from Chippenhook to Center Rutland over Boardman Hill makes a steep ascent diagonally across the western slope of the ridge. The outcropping rock along it is phyllite or schist, specimens of which at most places would not be distinguishable from similar rock at scores of places in the Sudbury hills. The schist outcrops appear in the road about a mile north of Chippenhook and thence continue along the road and east of it and farther north also in ledges west of it, to a point about a mile and one-fourth north of Flat Rock. Here the quartzite, which was mentioned above, crosses the road to Boardman Hill whence it continues northward west of the road and along it towards Center Rutland. Some outcrops of the phyllite appear east of the western outcrops of quartzite. The dip of the quartzite and the apparent dip of the schist is easterly. The boundary between schist and quartzite is in fact irregular and modified somewhat by promiscuous intermingling or interchanging of areas of schist and quartzite. Near and on Boardman Hill the ledges of quartzitic schist or thin-bedded quartzite show severe crumpling with small folds in more or less recumbent position, but more massive beds farther east have not been deformed so much, although the quartzite has taken on frequently a gneissic structure.

West of Flat Rock and Boardman Hill the western slope of the ridge descends to the valley of Clarendon River, first over schist, then on marble. Outcrops of the latter were noted near Austin's house between the 900 and 1,000 feet contours. Marble outcrops occur east and west of the stream and at one place along the road to West Rutland the rock is quarried (Clarendon Marble Co.) and at other places east of the stream it has been opened. But northward along the road the phyllite appears and intervenes between the marble exposures just mentioned and the great quarries of the Vermont Marble Co. at West Rutland along the valley of the head stream of Castleton River. To what extent, if any, the marble is interrupted in its north and south surface extension between Clarendon Springs and Center Rutland was not investigated.

Along the ridge north of Boardman Hill the quartzite was traced to within a mile of Center Rutland, but was not followed down the northern slope of the hill where it presumably occurs; for the rock was noted in the bed of the creek at Center Rutland.

About a mile north of Tinmouth village a gap in the range leads to Middletown Springs. Along the road the terrigenous rocks at the northern end of Tinmouth Mountain are precisely like those in the hills at the north in Hubbardton, Sudbury and Orwell, and while lithological distinctions may be drawn among the rocks in both places any separation on the basis of age seems impossible at the south as at the north, as well as between the two. About a mile west of the Tinmouth-Chippenhook road, "marbly" limestone appears. Its boundaries were not traced. It

seemed surrounded with terrigenous rocks, at the surface. No limestone was found at Ira, although it is reported from there and undoubtedly would have been seen by careful search.

As previously mentioned, east of Otter Creek near South Wallingford the steep slope of the Green Mountain plateau bends northeastward. The edge is marked southeast of Wallingford by a high scarp known locally as the "White Rocks." While the valley thus widens out between the plateau and the ridge that extends northward from Danby Hill, the western boundary in the eastern quartzite swings to the valley and is now marked east of Otter Creek and south of Wallingford village by the western edge of "Green Hill" which has the same general relation to the plateau that the valley quartzite has at Bennington, except that at north there are scarps in the valley as well as in the plateau. The scarps at the north have been freshened by ice action.

The rocks were not examined north of Wallingford village east of Otter Creek, between that town and Rutland. In the valley of Otter Creek no marble was seen between South Wallingford and Rutland; nor was any noted between South Wallingford and Danby. But the interbedded rocks were frequently seen from Danby Borough northward to Wallingford village, more particularly east of Otter Creek.

The quartzite which was noted in the bed of the creek at Center Rutland was found two-thirds of a mile north in the cut of the Rutland R. R. Later on a trip from Rutland city over Pine Hill to Proctor village this rock was traced from a point about one mile north of the outskirts of the city, from outcrops just west of the Pittsford road, up the eastern slope of Pine Hill along the cable line to the schist outcrops on the summit and higher western slope at the northern end of the hill. Schist was noted, apparently in place, while ascending the eastern slope along a wood road to the cable line.

The quartzite on the eastern slope dips easterly and eastward is overlain apparently conformably by dolomitic limestone, in which one reading gave the strike due north (magnetic) and the dip 42° easterly. As examined just east of the Pittsford road the limestone at places contains many grains and sometimes larger patches of silica. The quartzite apparently has some interbedded schist.

North of Pine Hill there is apparently a structural break, Pine Hill occupying the upthrow side.

At the northern end of Pine Hill the sharp descent on the west is over schist for a distance and then over calcareous rocks that apparently belong to the dolomite and dolomite-quartzite members of the Lower Cambrian, which around Proctor and southward, east and west of Otter Creek, are in association with marble. The interbedded rocks were traced northward into Pittsford, where their relations to the marble is the same as it is

around Brandon; outcrops of the marble occur east of the western margin of the interbedded rocks. South of the Brandon township line, except for a brief distance in Pittsford, the western margin of the interbedded rocks was not minutely traced in its relation to outcrops of marble. Around Proctor the interbedded rocks will often be seen in almost vertical attitude as has been described for the areas both north and south. Two and a half miles north of Proctor they were seen lying in an almost flat position. South of Proctor marble outcrops and has been opened along the lower western slopes of Pine Hill east of Otter Creek. Between these exposures and other marble outcrops farther west the calcareous members of the Lower Cambrian intervene, affording, apparently, another instance of exposure of marble by the erosion of its covering of Lower Cambrian rocks.

Otter Creek has clearly availed itself of structural features in its course, particularly around Rutland. At the city it turns from a northerly course to a westerly one as far as Center Rutland, whence it again flows northerly west of Pine Hill through Proctor and on to Pittsford.

The marble and the dolomite and interbedded rocks of the valley of Otter Creek, north of Center Rutland, lie between the mass of Pine Hill and a ridge of schist and phyllite. This ridge northward is broken to a slight extent topographically, but geologically joins with the quartzite-phyllite rocks in eastern Pittsford township, which in turn join with those of Brandon on the north and Hubbardton on the west. On the ridge west of Proctor village are some patches of "marbly" rock and a mile west of Fowler, farther north, is another patch of calcareous rock surrounded by the schist. Northward the terrigenous rocks are faulted at places west of Brandon, as has been described on previous pages, against the sheared blue limestones and marbles and finally disappear under these rocks in northern Sudbury township.

West of the schist ridge just mentioned lie the marbles of West Rutland between this ridge and the main mass of terrigenous rocks lying to the west in Castleton. In these marbles have been found bluish-gray rocks with abundant specimens of *Maclurea magna*. The calcareous rocks of the West Rutland valley extend as a narrow band about five miles long and terminate at the present surface at the north and south against the phyllite formation.

Westward the phyllite rocks along the Castleton River valley give place at the surface to the slates of Castleton and Fairhaven, but the slates are more or less associated with phyllite rocks just as they are north of Castleton in Hubbardton and Sudbury and north of Fairhaven in Benson, as described on previous pages.

Summary. Some of the details and some of the general relations which have just been given in the preceding description

of certain portions of the townships now being considered have been noted by other writers. The studies which have been only in part briefly presented by the writer, were made for the purpose of gaining from direct observation first-hand knowledge by which comparison could be made with the rocks and their relations at other places and really represent only a part of what it was hoped to make. They are offered for their general bearing on the question of the interpretation of the broad structural features of western Vermont.

In general it appears that the structural features of the different portions of the Vermont valley will have to be reconciled with each other. The assumption of similar genesis with respect to the main features of the valley throughout would seem to rest upon strong probability.

It further appears from features which have been and will be cited that the general structural relation of plateau to valley is the same all along the contiguous margins of the two. The Vermont valley now in its relation to the plateau is a downthrow region and a dismembered portion of the plateau. Probably this statement expresses only a portion of the truth, however, as it appears probable that the western side of the valley is faulted also, so that the valley is primarily a great structural trough between the plateau on the east and the mountains on the west. If this is the fact then in our thinking we must in imagination by taking account of probable displacement and erosion restore the valley floor to its approximate original position and in such way strive to visualize what the former relation of the plateau and the masses west of the valley would have been through the connecting mass which was displaced.

It may be asked, what evidence is there that the western side of the valley is faulted? West of Brandon there is evidence to show that the sheared limestones and marbles north and east of the phyllite hills are downfaulted, the fault being sometimes in the marble and sometimes between the phyllite and the marble. There is evidence on the east of Mt. Anthony in Bennington and Pownal of downfaulting of the valley rocks. It happens that along the west side of the valley it is not so easy to tie up some formation in the valley floor with one in the Taconic range as it is in the case of the valley quartzite with respect to similar rock in the plateau. At Dorset Mountain, however, we see the marble at its high level there and find its counterpart beneath the surface of the valley. With the fairly satisfactory evidence at the east of downfaulting why assume that Dorset Mountain has primarily been thrust up with respect to the valley? Dorset Mountain presents evidence by itself of displacement between it and adjacent rocks on the north and south. This fact rather argues against any such idea as that the whole region west of the plateau margin is downfaulted with respect to the plateau, which view might

permit the explanation of the valley as an erosion feature purely. There is no reason for selecting Dorset Mountain out of the Taconic region and assuming for it upthrow displacement with respect to adjacent rocks. On the whole it seems most probable to the writer that in view of the displacement between plateau and valley there was also displacement between the valley and the masses now at the west and that such is the significance of the relations shown at Dorset Mountain and at other places.

The marble is at different levels. In the valley it appears to be at about the same level at most places, but varies somewhat even there. In the Dorset Mountain mass it is much higher and perhaps repeated. In Tinmouth valley it is intermediate between its level in Dorset and in the main valley. This general statement of the levels at which the marble occurs refers only to the general Vermont valley region and its extension into the Champlain lowland and passes by for the moment the detached patches in the hills at the west.

The surface of the Vermont valley is controlled at various places by the peculiar structural conditions which there prevail. North of Bennington and through to Manchester, and in fact practically all along its eastern border, the Lower Cambrian rocks shape its surface. North of Dorset Mountain the main general valley widens and new features appear.

The steep northern slopes of Dorset Mountain, except as affected by general weathering, stream incision, and by drift, pass rather abruptly to a more gradual and gentle slope, which except for the incision of Mill Brook and the lateral erosion consequent upon it, continues without important change of level to the summit of Danby Hill and northward to Pine Hill and the schist ridge west of it in Rutland. This somewhat varying level marks a surface of intermediate altitude in a ridge intermediate between the plateau and the main mass of the Taconic range. This ridge is bounded on the east for most of its length by the Otter Creek valley and on the west by the valleys of Tinmouth Channel and parts of Clarendon and Castleton Rivers.

North of Dorset Mountain a region marked out by an east-west line just north of the mountain, a north-south line running probably along the western edge of the Tinmouth valley and its extension, another north-south line at the east, and an irregular line at the north, represents an area of downthrow in which the displacement has been differential. The intermediate ridge just mentioned is on the downthrow side with respect to Dorset Mountain, the plateau and the main mass of schist at the west, and on the upthrow side with respect to the rocks underlying Otter Creek. Its relation to the narrow valley on the west of it may be discussed later. Pine Hill is probably on the upthrow side with respect to the area in Pittsford north of it and potentially so with respect to the valley of Otter Creek south of it.

One of the first efforts at a restoration, such as has been suggested, of the original conditions prevailing between plateau and the mountains at the west would be to get the surface of the valley quartzite back at its former level, so to speak. If this were done all along the valley and lowland, beginning at Bennington and extending to Brandon, a great mass of rocks would be lifted. Along the eastern portion of the valley at least the calcareous members of the Lower Cambrian that now lie at places on the valley quartzite would be elevated to a level some distance above the eroded surface of the plateau and would in effect restore a part of the surface now gone from the plateau. Some account would have to be taken of erosion of the plateau, but the quartzite is a resistant rock.

Passing for the present what particular effects would be produced in the southern portion of the valley and in the region of the Champlain lowland, and considering only what would be the results in the regions of Dorset Mountain and the part of the valley north of it to Pittsford, the elevation of the upper surface of the valley quartzite even to the present sky line of that formation in the plateau would bring it to about the level of the schist-quartzite mass that partially caps Dorset Mountain. The calcareous members of the Cambrian would be above the quartzite. What is now beneath or adjacent to the quartzite which would be elevated with it?

In such an attempt at reconstruction there must necessarily be a large number of elements of uncertainty. This number should be reduced as much as possible.

We may assume, but only assume, that there has been no displacement between the marble of Dorset and that in the valley other than that which dropped the latter; or in other words, that the plateau and Dorset retain their relative positions practically unchanged since the displacement of the block between them.

If now we take the relations shown at South Wallingford of interbedded rocks resting on marble at their face value, and recall the conditions east of Brandon and those which apparently obtain around Proctor and Pittsford, it appears that in the neighborhood of Dorset Mountain we have probable overlap of the calcareous members of the Lower Cambrian on the marble. At Pine Hill we see a terrigenous mass consisting of a sort of conglomerate and a quartzite with interbedded schist, overlain by dolomitic limestone and interbedded rocks lying against marble at the west with the interbedded series apparently lying on the marble just west of the hill. The sequence which we have from the plateau through Pine Hill and the Center Rutland marble strip is not very different from that which is present east of Brandon; but at the south, west of the Center Rutland marble strip, we have conditions different from those near Brandon in

the presence of a ridge of schist intervening between the marble of the Center Rutland strip and that of the West Rutland strip.

In restoring the conditions in the valley east of Dorset Mountain it would appear that between the quartzite as elevated and the mass of Dorset there should intervene a narrow block of marble with interbedded rocks overlying it. In Dorset Mountain, schist with thick beds of quartzite tops the marble and the relative meridianal positions of the different rocks are made to correspond between the restoration of plateau to Dorset Mountain and what now prevails near Pine Hill.

The schist on Dorset Mountain and northward has usually been regarded as younger than the marble. The fact that it lies on the marble probably by itself is not a sure indication that it is younger; for it now appears practically certain that the marble is at many places in the valley overlain by Lower Cambrian calcareous rocks. The argument assumes that the marble is younger than the interbedded series of the Cambrian, evidence for which is had in the specimens of *Maclurea magna* of the West Rutland quarries, if the evidence as deduced from surface continuity for the Brandon region and as afforded from other relations is not conclusive.

On what does the marble of Dorset Mountain rest? It is sometimes represented as passing beneath a schist formation as though it continued indefinitely westward from the Vermont valley in that relation to the mass of schist composing the Taconic range and its foothills, and as though it passed at depth disconformably, or otherwise, into other calcareous rocks with Cambrian dolomites at their base. When the marble is found among the terrigenous rocks of the hills west of the valley it is explained as emerging from beneath, or as interbedded with the schist.

Examination of some of the patches of "marbly" limestone within the terrigenous rocks west of the valley often does not convey the idea of its being beneath, or of its being interbedded; but gives the distinct impression that it rests on the phyllite formation. In fact it would appear that marble rests on schist and that the latter rests on marble. The point would naturally be raised as to whether the schist above is the same as or like that below: that is, are limestone and phyllite usually really interstratified?

At West Mountain in Shaftsbury and at many other places within areas which are mapped as "Berkshire Schist," the prevailing terrigenous rocks are not distinguishable at all from those of other areas on which fossiliferous limestone, sheared, blue limestone, or "marbly" limestone now rest or certainly did rest at one time. In Brandon, Sudbury, Orwell and Benson are terrigenous rocks having to limestone the relation just mentioned, which the writer regards as so like the phyllites and schists of Danby, Clarendon and Rutland, that it is not possible to make

a sharp separation. They in fact join with each other at the present surface. These terrigenous rocks in Sudbury, Orwell and other places consist of interstratified schists, phyllites and quartzites. The schists which top Dorset are interbedded with thick beds of massive quartzite. Those which form the ridge from Danby Hill northward also seem to be.

If we accept as valid the evidence that has been offered on previous pages for a wide extension of calcareous rocks, including the marble along the Vermont valley and the Champlain lowland, over a terrigenous formation that is over large areas quite similar in its general characters and of probably similar age, and if on this basis we accept the idea that a section from the plateau westward is essentially the same, whether it is along a parallel passing through Leicester, Whiting and Shoreham, or along one through Dorset Mountain, Rupert and westward, except for differences of metamorphism of the limestone or the terrigenous rock and for differences in the present attitudes of the rocks, with consequent scarcity of limestone on schist at the south and consequent small exposure of schist through limestone at the north, and perhaps also for differences due to original lateral variation in the terrigenous rock, then if we think of the phyllite of the Sudbury hills passing beneath the marble of Brandon we may also think of it as passing beneath the marble of Dorset Mountain and that of the valley east of the mountain. In connection with conditions in the Vermont valley, we especially recall that at places among the hills at the west masses of limestone which rest on the terrigenous formation have also been preserved through protection by downfaulting.

The Vermont Report (page 412) states that "the limestone from West Dorset is continuous, through a notch on the west end of Mount Eolus, with the limestone and marble in the central part of Danby, upon the west range of the limestone formation." The map so shows it. Along the valley of the Mettawee a few miles due west from Dorset Mountain, as discussed on a subsequent page, limestone (here the dove-colored rock with gray dolomite) rests on the phyllite. The Vermont Report (page 412), apparently on the authority of the elder Hitchcock, gives the limestone as extending from Dorset over the mountain to Sandgate.

Accepting the idea of overlap along the eastern edge of the valley, from such evidence as we have, we have nothing to tell us how far the marble extends eastward beneath the older rocks. The important fact is that of overlap. If the marble lies on a quartzite-phyllite formation and practically the same kind of rocks now lie on the marble at any place in or west of the Vermont valley, one of the ways in which this relation might possibly be explained, involves an extension of the quartzite-phyllite for-

mation on which the marble lies eastward beneath the margin of the overlap.

An effort has been made to get before the reader a certain amount of evidence which goes to show a widely-prevailing relation between apparently related calcareous rocks and a terrigenous formation that is similar over wide areas and which indicates that the normal position is limestone on the phyllite formation. Attention was then called to the resemblance, as it appears to the writer, which such terrigenous formation has to similar rocks that have an inverse relation to the limestone and that now at certain places rest on it, that is, on marble.

It seems to the writer that a certain amount of assumption is involved when the schist on the limestone is called younger. We have seen that superposition may not be regarded as conclusive evidence in this region. The age of the "Berkshire Schist" seems to have been determined indirectly in all cases, either from field relations or in some other way. From relations which it has to limestones at many places it would seem clearly on such a basis to be older and in no wise interbedded. It has apparently been assumed that the Cambrian dolomite and dolomite-quartzite series passes directly beneath marble along certain parts of the Vermont valley and that the calcareous rocks thus make up a conformable or disconformable "Cambro-Ordovician" limestone series on which lies a conformable "Berkshire Schist." Such views, in the writer's opinion, leave in the air the explanation of such relations as overlap of the Cambrian rocks on the marble at numerous places; the undoubted superposition of related limestones including marbles on terrigenous rocks which are similar to and many of which are correlated with the "Berkshire Schist," and the relations which have been described in more or less detail for Orwell, Benson, Sudbury and Whiting. They further seem to ignore great thrusts, or at least, the wide extent of obvious movement of older on younger rocks, which the region everywhere exemplifies.

Even if the general and normal superposition of the limestone on the terrigenous formation over a wide region is admitted, it is not of course necessary on that account to give up the idea that the schist resting on marble is younger than the marble, because it is conceivable that conditions of deposition permitted the succession from limestone to terrigenous rock, or from terrigenous rock to limestone and again to terrigenous rock, perhaps over a wide region. Nothing in this summary has been said about the age of the quartzite-phyllite formation except that it often appears to be older as a whole, as now eroded, than the limestone which rests on it, including the marble. Further than the suggestions offered on previous pages the consideration of its probable age may be postponed.

One of the things that is perhaps confusing in explaining the relations along the Vermont valley on the basis of overlap by thrust of older rocks on younger ones is the fact that erosion apparently nowhere has uncovered a clear overlap of Cambrian quartzite on marble; something sharp and distinct like that of the quartzite on the "Utica" at Burlington. Another thing that is bound to be confusing, if it occurs, is overlap of terrigenous rocks on other entirely similar rocks, by thrust.

It has been implied above that the marble which underlies the valley, for example, that at South Wallingford, has been dropped from a higher level. North of Rutland the marble on the meridian of that of South Wallingford is apparently covered by the quartzite-schist and its overlying calcareous rocks in Pine Hill. At South Wallingford only the interbedded series can be seen to have any relation like that of overlap on marble.

The marble along Otter Creek north of Dorset Mountain has been assumed by some to pass beneath the intermediate ridge lying to the west and to emerge in the Tinmouth-Clarendon River valley. This is the view given in the Vermont Report. By others the intermediate ridge has been regarded as an anticline underlain by the basal Cambrian quartzite and the underlying pre-Cambrian and overlain by the "Stockbridge" limestone and "Berkshire Schist." Overthrust of Cambrian quartzite on schist is described and indicated and inclusion of limestone and schist in the older rocks is shown as occurring by the younger rock being faulted down into the older rock.

The structural pattern of the valley north of Dorset Mountain is unquestionably complicated and hard to analyze. It seems, however, that one of the first steps would be to try and make a restoration on the basis of the valley being a downfaulted region. Along the eastern side the Cambrian quartzite and interbedded schist could be thought of as elevated, carrying the Cambrian calcareous rocks above it and presumably at places at least, as at Pine Hill, the subjacent marble to a higher level. In other areas with more or less indeterminate boundaries on account of irregularity of early overlap the interbedded rocks of the Cambrian and its subjacent marble could be imagined as elevated. In still other areas, probably in different measure according to amount of displacement, the schist-quartzite masses of the intermediate ridge would be elevated, and by assumption, subjacent marble with it.

By these imaginary processes it would seem that we should get an extensive mass of marble over the area north of Dorset Mountain, approximately back to former levels one of which is now marked by the marble of the Dorset mass. It would seem, too, that the quartzite-schist of the intermediate ridge would be restored to a higher level and on this quartzite-schist with probably some overlying "marbly" limestone we should find a capping of dolomite and interbedded rocks, which we have come to asso-

ciate with the Lower Cambrian, the whole mass of Cambrian showing the buckling so characteristic of the interbedded series, as has been described so many times. We should recall that the same kind of deformation exhibited by the quartzite on the intermediate ridge is shown also by the quartzite east of Otter Creek, and that in fact one is the replica of the other. At places we now find lying on the schist of the intermediate ridge, small patches of limestone younger than the Cambrian, sometimes fossiliferous, sometimes "marbly," and it would appear that some of these were formerly overlain by quartzite, which in turn was and is now at places, overlain by the interbedded rocks of the Cambrian. In some places we now find all these various rocks within the space of a few acres, intermingling at the present surface, but in relations which suggest that the schist is lowest, the "marbly" or other limestone next, the quartzite next and finally the interbedded series. Underneath all, presumably, is other massive marble. Farther west in the Tinmouth valley are some indications that the interbedded series rests on massive marble, but this is not so certain; the massive marble may be deeper down. Except for erosion or lack of it, and minor details, this brief description would seem to apply to the whole ridge from Danby Hill north to Center Rutland. At Center Rutland the massive quartzite apparently swings to Pine Hill and does not touch the West Rutland ridge; but the latter presumably gives marble at depth, then the schist and on top of the latter, patches of marbly limestone, with possibly some of the interbedded rocks along its eastern base.

It would seem from such a restoration as has been attempted that north of Dorset Mountain there would have been overlap of Cambrian rocks as far west as Tinmouth valley, with younger rocks underneath. Sometimes this overlap apparently carried the interbedded rocks on the marble with no quartzite or schist intervening. Sometimes interbedded quartzite may have been carried over on schist with limestone or "marbly" rock intervening. Sometimes quartzite with overlying calcareous rocks may have been carried over the schist with "marbly" limestone intervening.

On the general idea of overlap of Cambrian rocks as just developed, recalling the conditions north of Dorset Mountain, it would seem that a restoration at Dorset Mountain would involve an overlap on its summit of calcareous members of the Cambrian series, perhaps on younger limestones that have been eroded.

The ideas developed up to this point clearly depart from the view that the Cambrian rocks of the valley, as now exposed, are members of a series that is subjacent to the schist-phyllite formation, and suppose rather that a portion of the Cambrian floor has moved from the east over on younger rocks and now lies by unconformable thrust overlap on younger strata. Overlap seems fairly plain; its extent is less certain. From what has been said

above it is further regarded as probable that the normal position for the marble is above a terrigenous formation like that which caps it. On this view the terrigenous formation is also beneath the marble of Dorset Mountain and extends eastward beneath the margin of the overlap of older rock and also beneath the valley marble, for an indeterminate distance, but perhaps not very far. How far is wholly problematical.

Now it seems possible to imagine that the conditions which seemingly would be present, after such a restoration as has been attempted was made, over the region under discussion, could be explained by a series of thrust displacements. The quartzite-phyllite formation and its overlying probably younger limestone were broken by reverse faults which probably were usually minor thrusts, and along the planes of these thrusts the quartzite-phyllite formation and the overlying younger limestone were driven westward through and over similar rocks until they came to overlie the younger limestone at the west. Or the plane may conceivably have cut in such way as to carry the phyllite against other but similar terrigenous rocks—cutting downward, for example, at places beneath the limestone, or into the terrigenous rock, and pushing the sliced-off portion on the "toe" of the thrust. It seems not difficult to imagine that there may have been several such thrusts, some of which may now be covered eastward and some of which may have been wholly or partly eroded westward. On meridians farther east a series composed of quartzite-phyllite with overlying dolomite and interbedded rocks was broken by reverse faults and finally, after ease of stress had been partly accomplished in this way, along an extensive, irregular plane, which truncated earlier planes within the series at depth and cut through different members of it, a great mass of rock was driven westward over previous thrust masses at the west and may possibly at places have overlapped several earlier thrusts. During these deformations probably some folding occurred as a result of compression and some perhaps as the result of friction along the surface of movement. On the hypothesis of repeated thrusting, as thus outlined, the possibilities of some of the marbles being separated from each other by thrust planes should be considered. During this overriding may have been the time when the marbles acquired their particular metamorphic characters which distinguish them from the apparently related rocks which carry fossils, or are less metamorphosed, and which lie, so to speak, west of the probable margin of the thrust overlaps from the east.

In the section from the plateau westward through Pine Hill apparently we should have, after restoration by elevation, quartzite-schist with overlying dolomite elevated along a reverse fault against the interbedded dolomites and quartzites, and the whole series cut by and resting along a thrust plane which had cut

through what is now marble overlying phyllite which together by a minor thrust had been previously and independently pushed over other calcareous rock now represented by the marble of the West Rutland valley, which may have its normal position on the terrigenous formation. These various rocks are probably now much disturbed from their thrust relations on account of later normal fault displacements.

Whenever the schist which had thus been thrust was brought by thrust or by later normal faulting against phyllite or schist which had been overridden it would probably not be possible, oftentimes, to tell the two terrigenous rocks apart, except possibly by difference in metamorphism of the moved rock.

South of Pine Hill minor thrusts would have broken and dislocated parts of the Lower Cambrian series with respect to each other and another deeper thrust would have truncated these; but the various thrusts, cutting and thrusting here in different ways from those at the north, would presumably have produced the peculiar minor features present at the south. The overlap of Cambrian on the marble would, however, have been produced.

If at some subsequent time these overthrust rocks were broken by differential tension faulting and dropped, as has been argued, the marbles under the overthrust would have been carried down, except at Dorset Mountain, perhaps, and at other places south of it, and after erosion we should see the conditions as they are today. It seems possible that portions of the main part of the Taconic range may be overthrust masses that are now protecting younger limestone (marble) at depth. West of the preserved overthrusts the limestone, because unprotected, has largely disappeared by erosion.

BENNINGTON AND RUTLAND COUNTIES.

Townships of Shaftsbury, Arlington, Sunderland, Manchester, Dorset, Rupert and Pawlet.

(Equinox, Londonderry, Wallingford and Pawlet topographic sheets.)

Topography. The areas examined in these townships lie mostly in the Vermont valley or that of the Mettawee River. For the most part the topography has been sufficiently described in speaking of the physiographic divisions of western Vermont.

Observations in certain parts of the Vermont valley through northeastern Shaftsbury, Arlington, Sunderland, Manchester and Dorset. The observations of the writer to be noted of the exposures and relations of the rocks in the towns mentioned in the heading of this section were made chiefly along the eastern part of the Vermont valley. The rocks along the western part were only casually inspected. It was the purpose to make a more

PLATE XXXIII.

Small fold illustrating structure frequently seen in the interbedded and dolomitic rocks of the Lower Cambrian series along the east side of the Vermont valley, but less plainly shown in larger folds on account of abrasion. This view is two miles east of Arlington. Equinox Mountain in the distance.

PLATE XXXIV.

Terraced plain and kame deposits a mile and a half northeast of Manchester Depot, east of the Batten Kill, showing the occasional character and the thickness of the modified drift covering in parts of the valley. The deposits were probably marginal and in part a delta-plain formation in a lobe of the ice sheet. View looking north up the Vermont valley. Photograph taken from the west slope of a kame.

critical examination of them later during the same season (1918), which illness prevented, in connection with the mountain rocks on the west side of the valley.

The surface covering is heavy along the eastern side of the valley most of the way from Shaftsbury to Manchester. On this account it did not prove possible to work out much concerning the precise interrelationships of the hard rocks.

The interbedded dolomite-quartzite series of the Lower Cambrian as seen in the eastern parts of Bennington and Shaftsbury was traced northward into Manchester and it was noted that the rocks continue to show northward at many places the characteristic topographic form of elongated arches which will be described for the areas at the south.

East of Shaftsbury village the folds of members of this series exhibit overturning to the west as was noted so often farther south and which is a very characteristic attitude which has been acquired by these interbedded rocks along the valley. Plate XXXIV shows this overturning on a small scale and in this case is a perfect replica of what occurs all along the valley on a larger scale, but which in the larger folds is obscured by abrasion. Any further description of these hills of the interbedded rocks throughout their extent from Shaftsbury to Manchester would be largely repetition.

It should be noted that the hills of these rocks do not lie snugly along the base of the slope of the Green Mountain plateau that fronts the valley on the east, but are separated from it by a space of varying width in which there is much modified and other drift material.

East of East Arlington village, north of "Kansas," streams have worn through from 75 to 100 feet of sand and gravel without exposing the basement rock. Plate XXXIV shows the present character of some of the kame and terrace covering that surrounds the hills of Lower Cambrian rocks and apparently overlies other parts of the series. Other areas are bowlder strewn and have apparently a relatively thin covering of bowlder drift. The quartzite and overlying members of the Lower Cambrian, in relations like those in Shaftsbury and Bennington, doubtless underlie the drift and the series probably extends all along the eastern side of the valley through these towns.

Quartzite was traced at several places up the steep slopes of the plateau. All the relations indicate that the valley rocks are dismembered portions of the plateau as is the case at the south near Bennington and at the north near Brandon. Although the quartzite was not noted in the valley between Bennington and Manchester in actual surface outcrops, southeast of Manchester the abundance of quartzite bowlders over certain areas suggests that the quartzite is not far below the surface there.

The Vermont valley widens out in Manchester and about 4 miles north of Manchester Center, marble outcrops extensively

at the surface and is worked in quarries at South Dorset. Other quarries have been opened between South Dorset village and the southern base of the Dorset Mountain mass and still others high up on the southern slopes. While the quarries at South Dorset are in some cases below the 1,000 feet contour, some of those near Owl's Head on Dorset Mountain are about on the 1,900 feet contour.

The different elevations at which the marble is worked on the south of the Dorset Mountain mass and the topographic outlines suggest a probable displacement by which the marble of the valley has been dropped from a higher level.

At the old Norcross quarry (see plate XXXV) a certain thickness of dolomite now rests with sharp contact on the marble and is well exposed in the north face of the old part of the quarry. The dolomite is infolded somewhat with the surface of the marble. The rock has much the same relation that a similar rock has to a marble in Swinington's quarry at Leicester Junction, which is right on the western margin of the calcareous members of the Lower Cambrian series in the township of Leicester.

In the quarries examined around South Dorset the marble shows the same internal deformation in the form of flow structures that marks the marble nearly all the way along the Vermont valley. It is in contrast to the interbedded series of the Lower Cambrian just as it is near Brandon. It is more metamorphosed in most cases than the dolomite that at certain places lies on it.

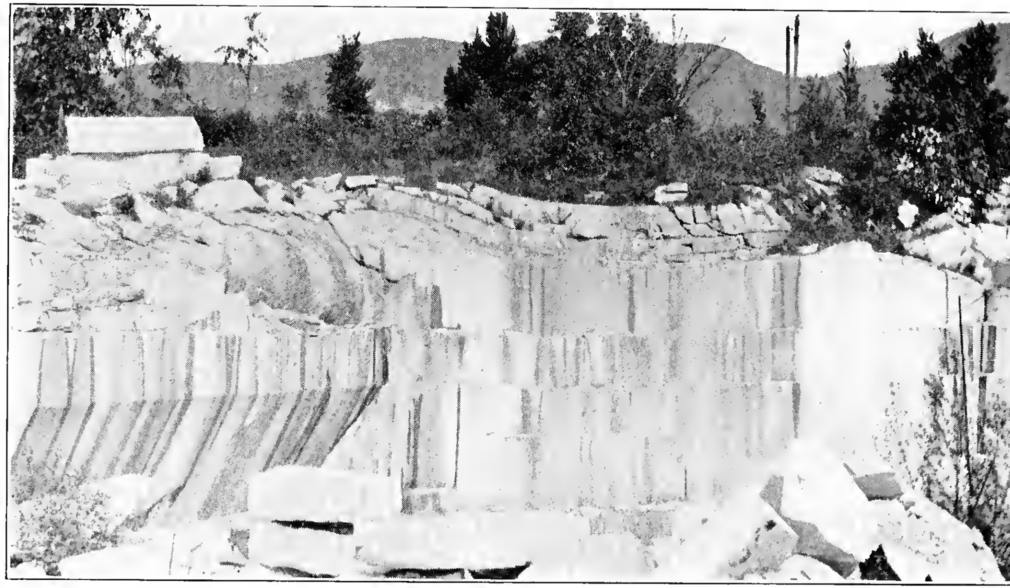
Observations along the valley of the Mettawee in Dorset, East Rupert, North Rupert and Pawlet to Granville, N. Y. Scattered observations were made along the valley of the Mettawee from South Dorset to Granville, N. Y. Some features of interest were observed.

Limestone or marble was noted along the road a mile east of East Rupert.

From East Rupert to North Rupert the hill slopes along the valley road were only casually inspected, but no difference was noted between the terrigenous rocks that compose them and those which have been described on previous pages for the hills in the northern part of the range.

Northwest of North Rupert the hill slopes on the south side of the road were more carefully examined. Here are the black and light-colored phyllites, the crinkled and more massive quartzites, making up precisely the same assemblage as to be found in the Sudbury and Orwell hills. They cannot be told apart. Two and a half miles northwest of North Rupert, south of the valley road to Pawlet, at the end of a short, blind road, limestone rests on the phyllite. A mile north, south of the main road, are excellent exposures of dove-colored limestone with gray patches of dolomite and other exposures in which the gray rock makes up practically the entire visible mass. More careful examination than

PLATE XXXV.



A portion of a stratum of dolomite now seen resting upon and folded with marble in the old Norcross quarry at South Dorset.

the writer was able to give on a day's tramp would undoubtedly disclose more extensive outcrops of the calcareous rock in a relation to the phyllite similar to that which has been noted at so many places.

From the outcrops last described, the hill slopes along the road through Pawlet give the phyllites. At Indian Hill and a mile east of it along the road are crinkled quartzites and light-colored, siliceous phyllites.

From North Pawlet a fine series of scarps can be seen bounding Burt, Cleveland and Lincoln hills and Pond Mountain on the west, and an east-west scarp on the south of Haystack Mountain.

Summary. Whatever its meaning may be, a section from the Green Mountain plateau east of Manchester carried northwesterly through Dorset along the valley of the Mettawee to Granville gives a repetition of the section from the Green Mountain plateau east of Brandon carried over the Sudbury and Orwell hills with certain differences that are less impressive than the resemblances. The Lower Cambrian rocks have practically the same relation to the marble, the calcareous rock rests on essentially the same terrigenous formation, and the latter presents the same difficulty of division into parts on the basis of age or other characters. More slate appears in the southern section (west of North Pawlet) and because of size of exposure permits easier arbitrary field division and mapping, but similar slate occurs in the northern section at several places.

The Vermont valley and eastern slopes of Dorset Mountain in Dorset and southern Danby. The valley narrows north of Manchester between the plateau and the mass of Dorset Mountain. The interbedded series continues northward in the narrow space between the steep western slope of the plateau and the abrupt eastern slope of Dorset.

In East Dorset village along the road and just above the buildings of the East Dorset Marble Co. are beds of dolomite. At the later place they pitch in a northerly direction. The writer was unable to decide what this dolomite represents, unless it is below the interbedded series and a part of the Cambrian.

North of the road from East Dorset village up the eastern slope of the mountain (Green Peak) and some distance up the slope the interbedded series is plainly visible. The writer's notes give a westerly dip for these beds at a point well up the slope. Schistose limestone with some slaty rock were noted a short distance up the eastern slope from East Dorset station near the road.

The eastern slope of the mountain impresses one as being bounded by normal faults. The great apparent thickness of calcareous rocks that appears along the slope may be due to displacements along more than one plane as the rocks now in the valley at the east and south were dropped, leaving the marble

and associated rocks after erosion in view at the higher levels and the interbedded rocks at the surface on the lower slopes and in the valley where the marble is now concealed beneath them. The idea of faulting is borne out by the general relations roundabout as well as by the aspect of the mountain slope itself.

The marble on the east face of Green Peak and northward is quarried at about the same level as that at Owl's Head. The fact of the same general level for the quarries may be made out from the valley road. At the Dorset Hill quarry the same features of metamorphism that have been mentioned for the marble elsewhere were noted, as also the facts that while bedding is now largely gone and flow structure and crystallinity have been induced, the marble stratum or mass lies in a flattish position as a whole, indicating that the metamorphic structures which it shows were probably induced under confinement of the mass and suggesting that similarity of relations or conditions prevailed over the wide area in which similar marble now occurs while these features were in process of formation.

Overlying the marble in Green Peak and northward practically continuously to Dorset Peak, is the so-called "Berkshire Schist" which, it is here interesting to note, is really a mass of interbedded schistose and phyllitic rocks with thick beds of quartzite and which as a whole, except for their aspect of somewhat greater metamorphism, do not look conspicuously unlike the quartzite-phyllite assemblage of the Hubbardton, Benson, Orwell and Sudbury hills.

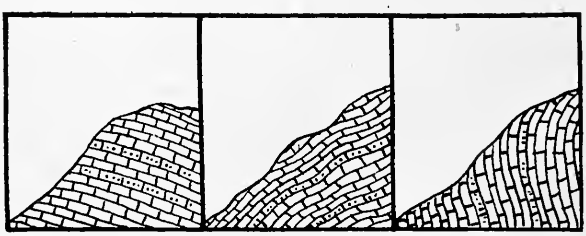


FIGURE 18. Sections to show different attitudes at different places of the interbedded series of the Lower Cambrian along the summit of an anticlinal ridge in the valley between Dorset Mt. and the plateau.

In the valley two miles north of East Dorset and east of Dorset Pond, on the strike of the northward-pitching dolomites at at East Dorset station, light-gray dolomite of the interbedded series forms a ridge. The rock is rather thinly-bedded at many places. Along the summit or upper portions of the western slope the beds may at one place be seen dipping rather gently easterly, at another westerly, and still another standing on end or dipping easterly at a high angle (figure 18). There has clearly been overturning to the westward, as is indicated by the variations in the dip of these anticlinal beds along and near the axis of the

fold. The same structure in these interbedded rocks is shown in the narrow valley here as in the wider portions at the south and north.

North of North Dorset a clear scarp defines the basal portion of the eastern slope of Dorset Peak. The ridge of interbedded rocks described in the preceding paragraph continues northward east of the railroad track for two miles north of North Dorset and then drops gradually off into the lowland of Otter Creek. Near its northern termination it is marked on the west by a moderate but steep scarp. West of the track and the highway, a hill of the same rocks rests against the scarp at the base of Dorset with a low scarp on the south. These rocks appear greatly crushed.

In the Vermont valley in Dorset one finds in the same rocks evidence of strong compression and also of displacement by normal faulting. Along the lower contours some of the scarps have been cleaned apparently at a relatively recent date. Erosion prior to the glacier had so softened the outlines of the higher eastern slopes of Dorset that although they are now steep, the probable fault planes do not now emerge as pronounced scarps even after ice action.

The observer is impressed in Dorset, as elsewhere, with the contrast between the plainly-bedded although withal strongly-folded Lower Cambrian rocks and the severely altered marble, and, in addition, senses some important structural significance in the presence of the high mass of this Taconic mountain flanked by Lower Cambrian quartzite so close to the plateau, and the narrow valley in between surfaced with the upper members of the Lower Cambrian series which also extend up the eastern slope of Dorset Mountain.

BENNINGTON COUNTY.

Towns of Pownal, Stamford, Bennington, Woodford, Shaftsbury and Glastenbury.

(Bennington and Hoosic topographic sheets.)

The geological relations in southwestern Bennington County were examined by the writer in 1912 and made the subject of a paper entitled, "Notes on the geology in the vicinity of Bennington, Vt."[1] The map and descriptions therein given included the township of Bennington, the major parts of Pownal and Shaftsbury, and portions of Stamford, Woodford and Glastenbury. It will therefore be convenient to review under one heading certain relations described in the paper mentioned which bear upon the present discussion, as well as to place on record some later observations made in the region and to offer some modifications of conclusions previously offered.

[1] Ninth Report of the State Geologist, 1914.

Topographic features. This area includes the southern portion of the Vermont valley, which is hemmed in on the east by the steep slope of the plateau except where this is cut by the valley of Walloomsac Brook. East of Bennington and north of Walloomsac Brook the western margin of the plateau is offset to the west about two miles from its course south of the stream.

The valley narrows south of Bennington and is intercepted by a ridge of schist which separates it from the valley of Hoosic River that enters Vermont from the Berkshire valley in Massachusetts. This schist ridge abuts against the plateau in Pownal. Thence it extends northwestward and terminates in Mt. Anthony in Bennington. The valley which comes down from the north through the towns of Manchester, Sunderland and Shaftsbury is bounded on the west by a high range which terminates west of Shaftsbury Center in West Mountain. Between West Mountain and Mt. Anthony is a wide open valley area which marks the extension of the Vermont valley into the Hudson valley region.

Relations southeast, south and southwest of the town of Bennington. In Stamford Mountain a gneiss that is believed to be of pre-Cambrian age is exposed at many places. Flanking this gneiss on the west and also extending around the southern end of the mountain into Massachusetts and then northward into Vermont again on the eastern side of the mountain is quartzite, which at many places in what appear to be basal beds is a massive, coarse, white, granular rock or a massive, compact, thick-bedded, brown formation. This passes upward into thin-bedded, schistose quartzite.

Glastenbury Mountain, north of Stamford Mountain, is also flanked on the west by scarps of quartzite. Faults separate these mountain masses from each other and bound them on the west. At the bases of the scarps on the west of the plateau lies a series of rocks which, when all members are present, has a quartzite at the base, essentially similar to that of the plateau, overlain by a certain thickness of dolomitic limestone, which is succeeded by an interbedded series whose members are sometimes dolomites, sometimes calcareous quartzites, and sometimes almost pure quartzites. Unless disturbed these rocks apparently are conformable.

When the series just mentioned was first described by the writer, owing to the limited time which was spent in areal mapping and lack of opportunity to check up certain portions of the area, it was not possible to speak positively respecting the westward extension of the series and its present western surface boundary. Much of the calcareous rock outcropping in limited exposures through the heavy surface mantle, in the western half of the valley, both north and south of Bennington, was simply termed limestone, in the absence of certainty as to correlation with the interbedded series or its subjacent dolomitic limestone, or of any fossil evidence as to age.

As surface outcrops this interbedded series is present in greatest force and is best exhibited northeast of Bennington. As first mapped by the writer it was shown as a rather regular strip about two miles wide along the eastern side of the valley northeast of Bennington and as a somewhat narrower strip southeast of Bennington, with its western boundary and the relation of the calcareous members to the quartzite not clearly defined. South of Bennington a strip about two miles wide was shown as "limestone formation," with only two rather limited exposures of the inbedded rocks at somewhat widely separated places along the eastern edge of the strip. At one of these places, which is southeast of Barber's Pond, the rocks are overlain by a black, shiny, graphitic-looking phyllite, which appeared conformable to the underlying beds. This is the only place in western Vermont which the writer has noted where the interbedded series is overlain by a schist or phyllite.

In Pownal the calcareous rocks of the valley are intercepted or interrupted at the present surface by the schist of Mason Hill and by the quartzite of the plateau which come together along a fault plane.

From their relation to the quartzite in which Lower Cambrian fossils have been found the calcareous rocks of the series just described are regarded as of Lower Cambrian age.

Some revision of the writer's previously-held ideas has proved necessary for the extension of the Lower Cambrian rocks around Bennington. Observations which were made during a short trip in the season of 1920, after a further acquaintance with Vermont rocks had been gained, may be offered here as some of them have an important bearing on the present paper.

Just south of Main street in Bennington, near the cemetery, dipping easterly at an angle of about 54°, are beds which were originally called simply limestone, but which now are regarded as members of the interbedded series. Similar beds outcrop along the road leaving Main street for Camp corner and again in a quarry besides the road three-fourths of a mile south of Main street. In the latter place the beds can be seen to be greatly disturbed and standing at a high angle, apparently overturned. One-half mile south of this quarry, on the northern slope of the hill, the same rocks lie in a flattish position, showing hardly any buckling and apparently pitching slightly to the south. One mile south-southeast of these flattish beds the interbedded rocks stand on end about 40 or 50 rods west of the old lumber mill on South Stream.

Within less than a mile therefore, east and west across the strike, allowing for a few offsets north and south within a mile, the interbedded rocks pass from a closely-compressed fold through almost flat position to highly inclined beds. It is certain that the drift conceals disturbed structural relations among these

beds. Along the hill road from Bennington to Morgan's corner and in the fields outcrops are few. Along the east-west road from Morgan's corner to the main road from Bennington to Pownal were observed some westward-dipping beds which were also apparently members of the interbedded series.

About two and a half miles south of Bennington, just south of Robinson's cross-roads and west of the main Pownal road, a hill shows a series which was examined and finally assigned to the interbedded stratum. The rocks are largely dolomitic but carry some siliceous beds. They dip westerly on the east side, but westward within the distance of half a mile the rocks show confusion and brecciation and then a marked change in the character of the rock, which will be described beyond. The confusion and brecciation are approximately on the line of strike of greatly brecciated rocks two miles to the north near Bennington.

It further seemed to the writer that certain calcareous beds and associated rocks, two and a half miles south of these outcrops in the hill just described, north of Pownal Center, at the base of the hill road running westward to Petty Corner, also belonged to this interbedded stratum. Perhaps a hundred and fifty yards up the steep hill, in the bed of the brook, south of the road, are quartzite, schistose quartzite and sericite schist or phyllite, apparently all conformable with each other and dipping easterly at a low angle near the top of the hill. At the top of the hill along the road to Petty Corner and northward along the road west of Carpenter Hill are ledges of sheared quartzite and quartzitic schist which the writer now considers to be of probable Lower Cambrian age from their resemblance to other rocks in the region. When first described and mapped in 1912, these rocks were simply designated as a part of the terrigenous formation that forms the Mt. Anthony-Mason Hill ridge.

The writer would now draw the western boundary of the Lower Cambrian calcareous rocks of the valley, from Pownal Center north to the Pownal township line, close to the base of the schist ridge.

The observer passing along the main road from Pownal Center towards Bennington would hardly fail to note the low but steep, eastern, scarp-like margin in the ridge which extends from just north of Pownal Center north to Carpenter Hill. At Pownal Center the schist-quartzite formation crosses the highway to join the schist of Mann Hill. The scarp just mentioned is low at Pownal Center but increases in height northward. At some places the members of the calcareous series give a false impression of passing beneath the quartzite-schist formation of the ridge, but at other places they seem rather clearly to be faulted against it. The rocks at the surface of both valley and ridge from Pownal Center to Carpenter Hill now appear to be members of the Lower Cambrian series of the general region. It is

the writer's opinion that an east-west section at the surface in the northern part of Pownal township from the quartzite of the plateau across the valley to and including the terrigenous rock of the eastern part of the ridge probably gives only Lower Cambrian rocks.

In Pownal Center along the road to North Pownal is a schistose quartzite, which from the coarseness of its laminations might be called a quartzitic gneiss. To the writer it appeared quite the same as other rock found in the plateau and at other places in the Taconic hills. This rock gives place westward to blackish, pyritiferous, gritty schist or phyllite. The latter, greatly crumpled and jammed and carrying much quartz in seams and bunches, occurs along the western slopes of Mann Hill and is particularly well shown along the highway and trolley road from Pownal to North Pownal and in cuts along the road from Pownal to Pownal Center. The rock at the summit of Mann Hill is a silvery, often greenish, sericite schist. Its apparent counterpart was observed, one and a half miles north of Pownal Center in the beds of the brook coming down from the hill south of the road from Petty Corner to the valley road, and was there apparently interbedded with schistose quartzite, (see above).

The schistose quartzites, gritty schists and black, pyritiferous phyllites of this ridge, at least from the latitude of Carpenter Hill southward, bear close lithological resemblance to rocks which are very common in the hills of the northern portion of the Taconic range and which are described above. The lighter-colored, finer-grained, more homogenous, siliceous phyllites common at the north were not so frequently observed in the exposures examined in Pownal.

It is very hard to decide on the basis of lithology alone whether all the schist and phyllite belong to one formation. It seems clear that field relations among the various rocks may simulate something very different from what they really are on account of complex deformation and that in the absence of definite criteria, assignment must be made on the basis of probability. It has been particularly noted above that in the Taconic hills farther north in Benson, Orwell, Sudbury and Brandon the black phyllites, finer-grained, light-colored, siliceous phyllites, grits and schists appear to pass into one another at the surface and that it becomes practically impossible to discover any particular arrangement or field relations among any of them that could be used to separate them as belonging to different formations or terranes. Moreover, in the Bennington region on West Mountain in Shaftsbury, the schist formation carries the lighter-colored phyllite with the other members and it appears to be still an open question whether the schist formation of this mountain is in whole or in part Lower Cambrian as mapped by Walcott, or Ordovician as

mapped by Dale and formerly suggested also by the writer (1914).

East of Pownal Center, on the northeastern slope of Mann Hill, limestone rests on the schist in patches and the two show much intermingling of outcops and great confusion. It was not possible to make any correlation of the limestone on the basis of lithology. The dip of schist and limestone often seem the same. Near Irish corner some early notes indicate the presence of a bluish or dove-colored limestone carrying gray patches like the rock to be described beyond.

At North Pownal village a scarp of limestone begins a short distance south of the mill of the Pownal Lime Co. and runs northerly parallel with and east of the main road through the village to Whipple's corner. In the quarries of the Pownal Lime Co. the limestone is without definite bedding, appears mashed and shows black, pyritiferous phyllite overlying it and jammed in with it. Plate XXXVI.

Under the highway, between it and the raiload track, in North Pownal village is greatly crumpled schist and the limestone seemingly rests on it. Although no contact was observed here two miles south, west of the Hoosic River, limestone and schist were found in relations which permitted no other interpretation than that the limestone rested on the schist formation. East of the high limestone hill in North Pownal village there are occasional areas in which limestone and schist outcrops intermingle at the present surface. Except for some outcrops of dove-colored rock carrying wavy stringers or layers of quartz one-half mile north of Wright Bridge corner, nothing was observed in the limestone in the vicinity of North Pownal that assisted in its correlation. In the writer's first description, from the general field relations and apparently isolated character of this limestone, it was regarded as a faulted inlier. It will be referred to again in the discussion of the possible general structural relations of the Bennington region.

The rocks southeast of Bennington present some further features of structure and arrangement which should be mentioned.

The writer's first map showed the valley quartzite southeast of Bennington as bounded by a fault on the west and there is still reason to think from the flattish position of the interbedded calcareous and quartzitic rocks in the bed of South Stream, as shown near the lumber mill and nearby, that there is a rupture between these flat beds and the closely-compressed similar rocks that lie just west, as above described. What was shown on the map as valley quartzite southeast of Bennington may and probably does have at various places some of the calcareous members of the series resting on it, as is the case in the bed of South Stream; but east and southeast of Bennington stream deposits,

PLATE XXXVI.

Photograph to show the structure of the limestone at North Pownal. The picture shows how the limestone has been crushed. At the right, phyllite, a black, pyritiferous rock, is shown resting on the limestone and lower down as jammed in with it.

carried into the valley at the time of glacial flooding, largely conceal outcrops except as exposed in the beds of streams.

West of Harmon Hill the valley quartzite from a scarp in the gneiss dips gently westward and passes beneath this mantle of stream deposits, but southward on the east, along a strike fault plane within the valley quartzite, a scarp appears which continuing southward rises in altitude and seems to form the main displacement that separates the quartzite of the plateau from that of the valley.

No apparent distinction is to be drawn between the quartzite of the plateau and the valley. They are the same in all essential characters and one in fact merges into the other where a strike fault scarp, for example, along the edge of the plateau dies away into a slope or monocline of the plateau quartzite. In the writer's first descriptions of this region the obvious displacements along the western edge of the plateau were regarded as reverse faults by which the gneiss and its overlying quartzite were thrust up into younger rocks, with repeated breaks along the strike. The valley quartzite was also thought of as having been elevated independently against younger rocks at the west and dropped later by normal faulting.

While there seem to be probable ruptures in the rocks of the valley by which they now stand in displaced relations to each other, some modification of the original description, which the map therewith attempted to show, is necessary if the Lower Cambrian series has the westward extension suggested in preceding paragraphs.

In the first description of the region a sort of assumption was made that in the vicinity of Bennington there is now a considerable but unknown thickness of Ordovician terrigenous rocks at the surface. For the pre-Cambrian gneiss and its associated Lower Cambrian quartzite to have their apparent present relations to the so-called younger masses, reverse faulting was assumed to have occurred along what is now the western edge of the plateau and also along planes that now lie within the valley. To the writer there still appears much field evidence to bear out the idea of an elevation of the pre-Cambrian floor; but the deformation by which the rocks of the Bennington area, and of western Vermont generally, came to be as they are, seems to be capable of comprehension, if at all, only through the study of a wide region.

Southwest of Bennington town are numerous puzzling relations which bear upon both the stratigraphy and structure of the region.

In an area just southwest of Bennington, bounded by South street, Dunham avenue and the Pownal road, occurs a bluish or dove-colored limestone carrying many small streaks and patches of gray or chamois color, and associated with beds of

gray or light chamois-colored rock. These rocks have been noted elsewhere near Bennington, as will be discussed beyond. In one outcrop what appeared to be a few encrinal stem fragments were found. This rock is greatly sheared and near the Pownal road carries bands of brecciated limestone. On account of the sheared structure it was usually not possible to decide whether the eastward dip is that of shearing or bedding, in the sheared rock itself; although in one place the dove and gray seemed clearly to be interbedded and to dip easterly. In another place, perhaps two hundred yards south of mixed sheared and brecciated rocks, and along their general strike, were somewhat thick-bedded, gray limestones dipping westward about 20 degrees.

On the east side of the Pownal road, just south of the junction with Dunham avenue, dark, bluish limestone forms a ledge beside the road and the bedding planes can be distinguished standing at a high angle, sinuously bent along the strike and apparently slightly overturned. Strong shearing along many planes close together has greatly obscured the bedding and produced a sort of slaty limestone, (figure 19).

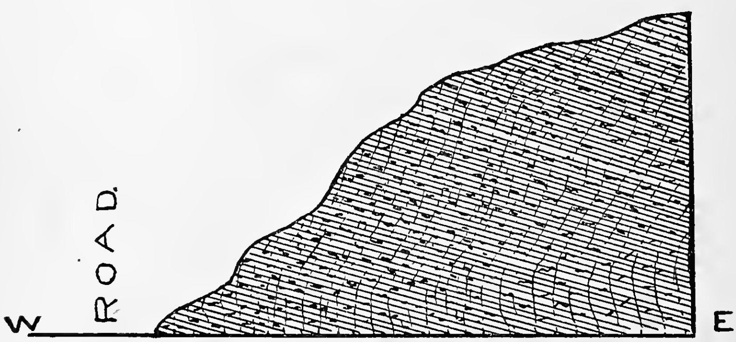
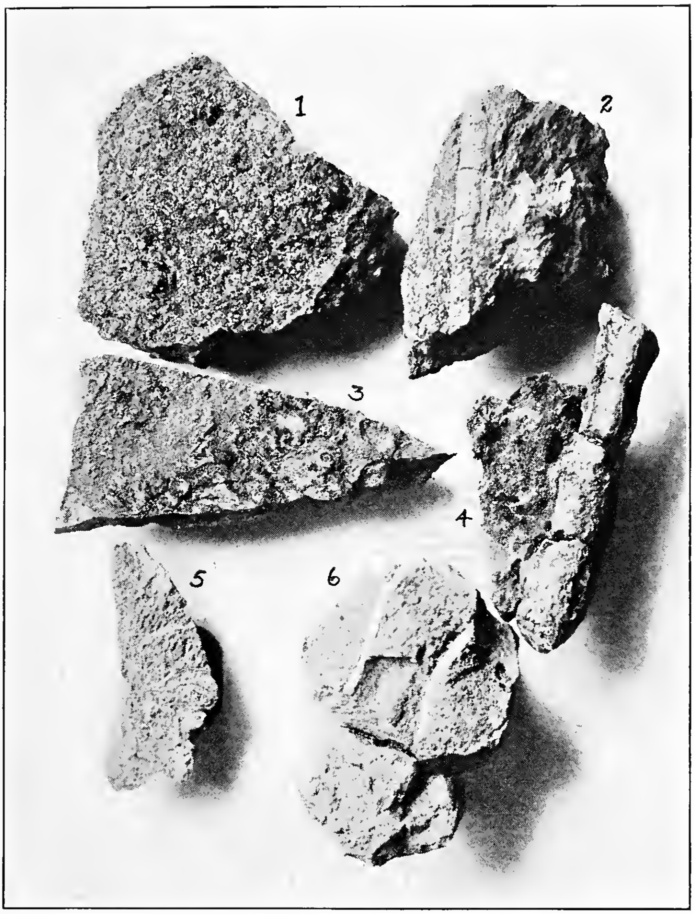


FIGURE 19. Schematic section of limestone as shown in a ledge near the junction of the Bennington Center-Pownal road and Dunham avenue in Bennington. Limestone is close to or involved in a zone of crushing and an easterly-dipping shearing has nearly obliterated bedding.

The general strike of the rocks just described is approximately north and south. Just east of the Bennington Center-Pownal road, in the fields between Dunham avenue and the next road north, are many ledges over an area several acres in extent, in which the limestone is greatly brecciated, some of the fragments being several inches in diameter. West of the Pownal road, a few hundred yards northwest of these brecciated outcrops, the limestone shows a strike of N. 81° W. and a dip of 24° southerly which correspond in general with the strike and dip of the heavy limestones and marbles that form the northern slope of Mt. Anthony.

PLATE XXXVII.



Various fossils found in the vicinity of Bennington. Numbers 1, 2, 3 and 4 collected in South Shaftsbury about 2 miles north of North Bennington village. Numbers 5 and 6 found 3½ miles south of Bennington town near Carpenter Hill. The forms are described in the text and are regarded as probably of Chazy age.

The sheared blue or dove-colored limestone described above is traceable, with long interruptions, from the outcrops north of Dunham avenue for two miles south-southwesterly to some ledges just west of the road over Carpenter Hill and one mile southwest of Robinson's cross-roads. At this place the sheared, patchy, dove-colored rock and its gray associate occupy a prominent knoll and form conspicuous ledges. In the blue rock were found distinct fossil markings, including a much-worn spiral of the size of and identified as *Maclurea magna,* a smaller probable *Maclurea* about two inches in diameter (fig. 5, plate XXXVII), and two specimens like that shown in number 6, plate XXXVII. On the basis of fossils and the resemblance of the rock to Chazy beds examined elsewhere in Vermont these rocks are put in that terrane and regarded as probably Middle Chazy. These rocks may be represented east of Pownal Center near Irish Corner, (see above).

North of these outcrops, along the eastern slope of Mt. Anthony the relations are very obscure. At some places, particularly towards the northern end, thick-bedded marbles dip westerly into the mountain. The dip changes northward to southwesterly and then to southerly. The mountain gives the appearance of being of synclinal structure with southerly pitch and of being composed of thick limestone or marble beds at the base, which are capped with schist. In a quarry in the woods on the east side of the mountain and west of the Everett mansion, and also in Colgate's quarry on the northwest side, along the North Pownal road, a blue, crystalline limestone stratum is seen to lie just beneath the schist. This rock is of uncertain thickness, but its strike and dip seem to indicate that it is conformable to the marbles below it. It has not been identified in the region in any other relations than those just described.

Notes taken in 1912 indicate absence of noticeable crushing in the schist at Everett's quarry and describe the contact between it and the limestone as apparently conformable. The phyllite contact was described as disturbed at places in Colgate's quarry, although in the northeastern part of the quarry a contact similar to that in Everett's quarry could be seen. Internal deformation in the schist is more apparent than in the limestone, as perhaps would naturally be expected, whether in place or not. The calcareous rocks beneath are all highly crystalline, but apparently not deformed like the marbles that have been noted as occurring farther north. The contrast which the calcareous rocks underlying Mt. Anthony, as well as others which occur north of it and have much the same dip, have to the sheared and brecciated rocks of the general vicinity is very marked and goes with other field relations to show that most of the strata of the region have been greatly disturbed.

It should be noted that the drift covering is heavy over the western part of the valley south of Bennington and that on that

account much uncertainty must exist as to the extent to which Lower Cambrian rocks form the hard rock substratum over this area. Moreover, there are outcrops of limestone over this region which cannot be assigned with certainty to the Lower Cambrian or to any other terrane. In the Bennington region what is immediately subjacent to the Lower Cambrian of the valley cannot be stated in any measure, so far as the writer's knowledge goes. Farther north in Vermont there is good reason to think that the marble formation, whatever its age, is overlain by Lower Cambrian rocks, as has been shown.

East, northeast and north of Bennington. It has not appeared necessary to modify in any essential particulars the relations as described in the author's previous paper for the areas east, northeast and north of Bennington. They may be very briefly reviewed.

A broad band of Lower Cambrian rocks extends along the eastern side of the valley under the scarp of the plateau. In its southern part, except for a small area of dolomitic limestone and overlying interbedded rocks near Bennington, quartzite forms the only surface rock over a distance of about 4 miles. In the southern portion of the band there is apparent a low southerly pitch and the arrangement of quartzite, limestone and interbedded rocks shows a conformable series, (figure 20).

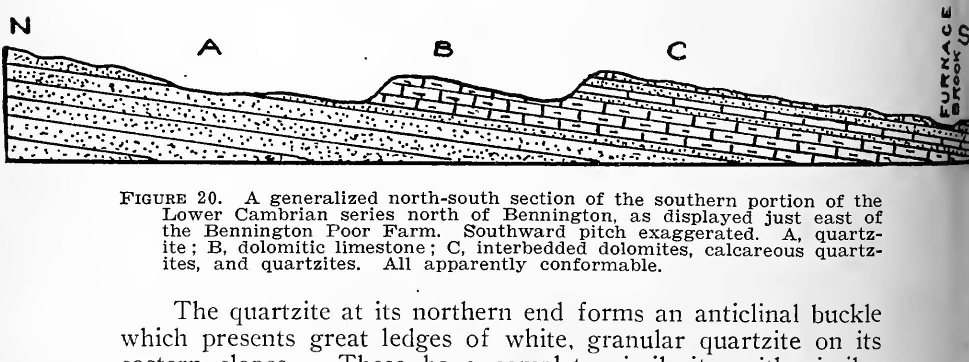


FIGURE 20. A generalized north-south section of the southern portion of the Lower Cambrian series north of Bennington, as displayed just east of the Bennington Poor Farm. Southward pitch exaggerated. A, quartzite; B, dolomitic limestone; C, interbedded dolomites, calcareous quartzites, and quartzites. All apparently conformable.

The quartzite at its northern end forms an anticlinal buckle which presents great ledges of white, granular quartzite on its eastern slopes. These have complete similarity with similar quartzite in the plateau just east of the valley quartzite and the latter is looked upon as a dismembered portion of that now flanking the plateau. Southward towards Bennington the coarser quartzite passes upward into somewhat thinner and more schistose beds and thus gives the same transition that may be observed on the western quartzite slope of "The Dome" in Pownal. On the west the surface slope of this valley quartzite descends across the edges of the beds.

At the north the valley quartzite just described, in the town of Shaftsbury, is apparently cut off by a tranverse fault. The quartzite is succeeded abruptly at the surface by limestone which

form a series of arches elongated along the strike. Farther north these are replaced by similar arches of the interbedded rocks. The succession going north is thus seen to be from quartzite through limestone to the interbedded members of the series; but the members have been more disturbed with reference to each other than is the case over the southern portion of the strip. Moreover, there is apparent a series of displacements along the strike as well as folding and faulting across it.

The arches described consist of compressed folds of limestone or of the interbedded rocks and the beds frequently show overturning to the west. The arches, including the one in the quartzite and those south of Bennington, are all of similar genetic type. Northward these arches give a characteristic topographic form to the surface of much of the Vermont valley as has been mentioned.

The members of the Lower Cambrian series north of Bennington, just described, were not positively identified in any part west of the westernmost exposures of its basal quartzite member as this outcrops along the South Shaftsbury road. Much surface material covers the rock northwest of Bennington in the central and western parts of the valley. The probable correlation of certain outcrops southeast of South Shaftsbury village and in the cuts of the Rutland R. R. north of the village is not now apparent. In the writer's map of the Bennington region a probable fault was shown as bounding the whole Lower Cambrian series on the west from Bennington north to the limit of the map. For the most part the line to mark this fault was drawn some distance to the east of South Shaftsbury road. Near Bennington, however, it crosses that road at the junction with the "Stony Hill road." The boundary as thus shown was drawn partly to emphasize the close age relations of the rocks forming this broad band along the east side of the valley and partly to record the surface features indicative of displacement along their apparent western margin at the northern end of the strip.

It might be noted here that some fragmentary outcrops of siliceous and dolomitic rocks somewhat resembling the members of the interbedded series were observed one and a half miles north of North Bennington village; but it did not seem possible to determine whether they are in place.

West and northwest of Bennington. The general southerly dip that marks the limestone and marble beds on the northern slope of Mt. Anthony was traced northward to and across the Bennington-Hoosic road and was noted distinctly three-fourths of a mile northwest of the monument at Bennington Center. While the rock in North Bennington, which will be mentioned presently, shows some difference in strike and dip from that south of it, the two bear resemblances with respect to absence of

pronounced internal deformation such as other rocks of the region show.

Along the banks and in the bed of Paran Creek, south of North Bennington village, the limestone beds have a strike, according to one reading selected as fairly representative, of about N. 80° E. and a dip of about 11° south-southeasterly. On the west side of the road west of the creek, opposite the office of the Cushman Furniture Company, are beds of dark gray limestone ranging in thickness from about two feet at the base of the exposure to about 10 inches or a foot near the top. Similar beds outcrop just below the dam of the Stark Paper Mill and above it farther up stream. No fossils were found and no correlation seemed justified on any basis.

In Shaftsbury a mile and a half north of North Bennington village, in the woods on an east hill slope, southwest of Twitchell's corner, were found a few ledges of the same sheared, patchy, dove-colored rock and its gray associate seen southwest of Bennington, west of the road over Carpenter Hill. The dip is westerly into the hill about 25° and the strike N. 40° to 50° E. The exposures are limited with drift all about. The dove-colored rock is plainly fossiliferous, but the markings are obscure. Spiral lines and patches representing coiled shells of some kind were noted at several places. These were hard to remove. Figure 3, plate XXXVII, gives an indication of the markings, but some of those found at the locality now being described were much more plainly shown to be sections of coiled shells. At this locality occurs a thin bed with abundant sections of small encrinal stems (fig. 1). This same bed at one place yielded two orthoceras-like specimens (figs. 2 and 4) which, however, it is hardly possible to identify. Some of the rock seen on surfaces cutting across the bedding is distinctly striped in appearance. It was at this locality that some fragmentary dolomitic and siliceous rocks, very limited in exposure, were noted. They bear some resemblance to the interbedded members of the Cambrian farther east; but from observations made about a mile farther west where more extensive siliceous beds seem to belong with a series which includes also the striped and dove-colored rocks, their Cambrian age was regarded as improbable. The fossiliferous rock and its associates are regarded as probably Chazy. It seemed likely that *Maclurea magna* might be found but a careful search did not reveal it.

Northwest of the limited exposures just described, over the hill, across a road and down a northwestern slope to a brook, for a distance of about a mile is nothing but drift. Just west of this brook and north of the road to Cold Spring Corner are low-lying ledges of black, pyritiferous phyllite. This rock passes northward beneath greatly jammed and distorted limestone in which the patchy, dove-colored rock appears again in association

with gray dolomite beds, which are infolded and otherwise involved with the other rock. These beds of limestone clearly rest on the phyllite. The deformation of the limestone beds is very severe; they are folded and overturned, profoundly sheared, jointed and mashed. Fossils have not escaped. In one exposure only, a small slab about 6 feet square, and perhaps not in place, although lithologically resembling some of the ledges and quite like some rock seen a mile east, showed some coils, most of which were thick patches but clearly fossils. A piece of this slab is shown in figure 3, plate XXXVII. The ledges at this place were similar to those described above as carrying fossils.

Westward across a narrow swamp, in some woods and in the field north, are many ledges of similar rocks, although interbedded quartzite is frequent here. These rocks have resemblance to some that were noted west of Brandon just east of the Rutland R. R. track on both sides of the road through Morgan's Stock Farm and also to some others on the strike of the latter on the west side of Otter Creek along the eastern margin of Long Swamp; also with others found west of Orwell village. These latter rocks in Shaftsbury were hard to correlate with others of the vicinity.

The suggestion is strong from the field relations that the phyllite mentioned above lies beneath all these various calcareous rocks north of the road to Cold Spring Corner.

It seems probable that the various outcrops of dove-colored rocks carrying gray patches and fossils, and the associated gray beds, and perhaps also those with the interbedded quartzite, belong to the Chazy, on the basis of similarity with the outcrops south of Bennington and at places northward in the State.

An especially interesting feature of the exposures in Shaftsbury described above is the subjacent position of the black phyllite, in view of relations which have been described for areas farther north. At places west and southwest of North Bennington the relations between limestone and schist afford reasons for thinking that the limestone rests upon the schist formation.

On the lower portion of the southern slope of West Mountain are calcareous rocks similar to those just described. They are greatly sheared and "splintered." Up the southeastern slope of the mountain the limestone gives place at the surface to phyllite. At the top of the mountain is a light-colored, siliceous phyllite very similar to rock found associated with quartzite and black phyllite in the Sudbury hills except that the former is more micaceous and schistose.

Summary of the Bennington region. Both the rocks and the relations which they have to each other in this region show many resemblances to those which have been described for the region around Brandon. There are also differences. In general the Lower Cambrian series along the east side of the valley, in its

lithological characters and its structural features, much resembles the other in each case. At Brandon black, and often pyritiferous, schist is associated with the quartzite along the plateau margin. At Bennington, except for a small patch lying on members of the interbedded series against the edge of the plateau, southeast of Barber's Pond, and the schist of Mason Hill, phyllite was not noted as involved with quartzite in proximity to the plateau. But it should be noted that much of the rock making up the Mt. Anthony ridge, south of the latitude of Carpenter Hill at least, is not to be distinguished from that found along the plateau east of Brandon. It is apparently the same schist which is found in both places and which also underlies the calcareous rocks described above north of the Cold Spring road in Shaftsbury. This schist has a marked similarity throughout a wide distribution, as has been brought out fully above.

A section south of Bennington, in Pownal, from the plateau on the east across the valley and the Mt. Anthony schist ridge, gives gneiss with overlying quartzite, faulted with quartzite and overlying calcareous rocks, which are faulted with each other. These latter rocks apparently extend to the base of the schist ridge on the west of the valley and here now apparently are faulted again against quartzite and phyllite which form the scarp and the surface rock along the eastern portion of the ridge. Farther west lies the limestone of North Pownal which is much involved with schist, sometimes intermingling with it in surface outcrops, sometimes underlying it, and here and there jammed in with it.

Another section north of the latter, passing through Mt. Anthony proper, shows sheared and brecciated limestones, some of which are of probable Chazy age, lying just west of the apparent western edge of the Lower Cambrian series and containing a long and strongly-marked zone of crushing, as well as the shearing characteristic of the whole mass, and west of this deformed strip gives the thick-bedded, crystalline marbles of Mt. Anthony apparently not greatly deformed internally, or as a mass, and overlain by schist in apparent conformity.

An east-west section north of Bennington, passing just south of North Bennington village, gives the Lower Cambrian as before, then an interval of unknown (drift-covered), then the flattish, dark gray limestones of Paran Creek. Farther west the indications are that limestone rests on schist.

A section passing about two miles north of North Bennington gives Lower Cambrian as before, an interval of unknown, then the rocks which were described above as probable Chazy and others associated with them. These at places lie on black, pyritiferous phyllite and probably are over much of the area now resting on the phyllite.

Farther north still, along a section passing through Shaftsbury Center or Shaftsbury Depot and West Mountain, the Lower Cambrian series lies on the east side of the valley, then certain limestones near the foot of West Mountain, then the schist of West Mountain. Except for one small patch just west of Shaftsbury Depot along the lower eastern slope, the schist of West Mountain was not found to have any limestone resting on it, although the writer's search was not exhaustive.

The Lower Cambrian series of the valley is clearly a dismembered part of a mass to which the quartzite of the plateau also belonged; whether the result of reverse or normal faulting has already been discussed for its northern extension. The evidence in this Lower Cambrian series shows that it has been under strong compressive stress, and that some of its deformational features are due to such stress. The conditions exhibited south of Bennington and in North Pownal show the action of powerful compressive forces in the region. Some rocks seem to be crushed more than others, as though caught and confined and made to deform internally because they could not get away. Other rocks seem to have escaped great internal crushing although metamorphosed by other processes, such as recrystallization.

The apparent minor displacements in the Lower Cambrian series, involving overturned folds and probable reverse faults, are evidence of former compression. The overturned folding in some cases, however, may have been due to friction instead of having preceded and initiated the rupture. In the Bennington region the evidence of upthrust of older into younger rocks is strong; but the evidence for lateral thrust, or better, lateral movement, is not so apparent. Farther north, marble that is almost certainly younger in age outcrops from beneath overthrust Lower Cambrian rocks. These relations were not established for the Bennington area. While the limestones west of North Bennington seem to be thrust on schist in some cases, and have undoubtedly been under compression, the field relations do not show that the limestone may not have rested on the terrigenous rocks prior to the deformation of the former.

In the writer's first description of the geology of Bennington, the character of the Vermont valley as primarily a structural valley was recognized; but the break between the plateau and the valley was regarded as primarily a reverse fault and the normal displacement producing the present relations was thought to have utilized the earlier reverse fault plane. This does not seem likely from the relations shown in other areas.

The present lateral distribution of the calcareous members of the Lower Cambrian series in the valley has no necessary relation to their original extension eastward or westward. Such extension must be decided by other considerations. The probability of primary upthrust of Lower Cambrian and of later

normal faulting of a part of the series, together with the fact of erosion, calls for an original extension of the Lower Cambrian series as a whole to the eastward. Whether they extend westward at depth is perhaps another question. Whether they ever had a great westward extension by thrust is certainly an independent consideration.

Certain other matters may be postponed until the general summary for western Vermont is offered. Enough has been said to show that the relations are complex and that one is practically driven to inspect other areas to obtain light on this one.

ADDISON COUNTY.

Whiting and Shoreham Townships.

(Brandon and Ticonderoga topographic sheets.)

Topography. These townships lie just north of the Taconic hills of Sudbury and Orwell, in the southern part of the Champlain lowland. The surface is low for the most part in Whiting; the eastern boundary of the township in fact for a distance of four miles is Otter Creek. In Shoreham there are a few low hills.

General observations in Whiting and Shoreham. There has been a much more extensive preservation of the limestone strata, which have been noted in fragmentary areas in Orwell, Benson, Sudbury and elsewhere, northward in the portion of the Champlain lowland extending through Whiting, Shoreham and neighboring townships. On this account, some of the relations and the ages of the various rocks were early worked out in these areas, first through the work of Wing and later that of Brainerd and Seely. In the town of Shoreham was established the type section of the Beekmantown of western Vermont.

In the course of his studies the writer reviewed some of the field relations in Whiting and Shoreham.

The phyllites north of Sudbury village at and around Webster corner, which have already been described, were followed northward along the road to Whiting village by frequent outcrops nearly to the village. Along the road running west two miles north of the village the same phyllites were traced from the school house on the Middlebury road past Hitchcock's residence to school house corner. In the valley of the brook one-fourth of a mile west of Hitchcock's place, the phyllite formation showed patches of quartzite with vein quartz like that on Government Hill in Sudbury and at other places in the Sudbury hills. In general no essential difference could be discerned between the rocks composing the low ridge which extends northward from Sudbury into Whiting and those which make up the hills of Sudbury, Orwell and Benson.

West of the phyllite formation in Whiting just described, the section described by Brainerd and Seely for eastern Shoreham can be fairly easily followed if side excursions are made frequently enough to get exposures of beds which are soil-covered at other places along the strike. The apparent monoclinal character with easterly dip and the apparent thickness as described, can be made out and duly appreciated.

One-third of a mile west of school house corner, mentioned above, the road which goes westerly past Hitchcock's place turns sharply to the south to join the main road from Whiting village to Shoreham village. Along and east of this road leading south are exposures of the blue Trenton limestone dipping easterly at an angle of about 40° and extending along the strike practically north and south. West of the road are ledges of the Chazy and others which have many similarities to the Chazy, but which Brainerd and Seely called division E of their Beekmantown. Along another road just west appears division D with many fossils at numerous places. Then follow divisions C, B and A westward over Cutting Hill towards Richville. Just east of Richville is exposed with easterly dip along the main road the whitish, quartzitic sandstone which was called the "Potsdam," and which is described as forming the base of the section.

At the bridge at Richville, east of the road and in the river bank, and northward the rocks show great confusion, and north of Richville at places beds belonging to division D show westerly dip just west of this zone of disturbance. As recognized and shown by Brainerd and Seely a fault or thrust has elevated the "Potsdam" against younger beds.

West of Richville the "Potsdam" outcrops again along the road to Shoreham, apparently along the axis of a ruptured anticlinal buckle for the sandstone apparently rests at the west against division C, and possibly D. This broken anticline, however, seems to belong to a larger mass of beds which has ridden westward along a deeper and more extensive thrust plane, cutting through the Beekmantown and still higher beds. Just east of Shoreham village, near and east of the Catholic Church, are Trenton rocks succeeded eastward by Chazy beds dipping westerly, which in turn are succeeded eastward by Upper Beekmantown, dipping at a high angle easterly, according to the writer's observations. It would seem that beds which stood at a high angle of westerly dip at the time of rupture would have had this increased and even reversed by the drag along a thrust plane.

In the center of the village the "Potsdam" appears again on the eastern margin of an extensive swamp which westward is succeeded by hills of "Utica" slates.

South of Shoreham in the town of Orwell, field relations which have been described above, indicate that a limestone series like that which occurs in Shoreham has been broken by reverse

faulting and minor thrusting which have brought the lower members of the series against and over higher ones, and that as now affected by erosion at some places the younger rocks are shown beneath and the older on top. Moreover, other more extensive thrust planes have carried the previously faulted series over still younger rocks on which it may now be seen resting at several places.

From the description of the relations as inspected in Whiting and Shoreham the similarity to the condition in Orwell appears. The same phyllites occur at the east succeeded westward by an unusually regular series of calcareous rocks from the Trenton down through the gray sandstone called the "Potsdam," while still farther west near the lake are hills of "Utica" slate. Except as affected by erosion the arrangement and sequence are apparently the same and it would seem that the structural relations of both areas must have been due to similar causes.

The conditions in western Shoreham and western Orwell townships raise two questions:

1. How is the preservation of the hills of rather frail "Utica" shales and included limestone bands along the edge of the lake to be explained unless by assuming their protection perhaps until relatively recent times by a more durable covering?

2. What explanation is to be given of the absence at the west of the phyllite formation found at the east beneath the limestones?

ADDISON COUNTY.

Townships of Leicester, Salisbury, Middlebury, Cornwall, Bridport, Weybridge, Addison, New Haven, Waltham and Vergennes.

(Brandon, Ticonderoga, Port Henry and Middlebury topographic sheets.)

Topography. The topography of the areas examined in these townships is for the most part typical of the Champlain lowland. Snake and Buck mountains are somewhat conspicuous elevations whose structural significance will be discussed beyond.

Observations between Lake Dunmore and Snake Mountain. In the summer of 1918 two days were spent in as careful an examination as a walking trip would permit of the country between Brandon village and Vergennes. The first part of the trip was along an irregular traverse from Brandon by way of Lake Dunmore to Snake Mountain through the townships of Leicester, Salisbury, Middlebury, Cornwall and Weybridge.

North of Forestdale the western boundary of the quartzite formation swings from the plateau to the Champlain lowland and marks the beginning of a westward extension of this formation that in the lowland becomes even more pronounced at the north in Monkton.

The structural breaks between the plateau and lowland north of Brandon exhibit their own peculiar pattern, but in it can be discerned a similarity to that at the south, in the overlapping along the strike of normal fault displacements of varying throw. Northward the western margin of the plateau is farther west than it is east of Brandon. The dismembered portions of the quartzite, or rather the Lower Cambrian series, along the eastern margin of the lowland take the form of hills and ridges which begin west of Lake Dunmore and gain in prominence northward. In general the relations are similar to those shown along the eastern margin of the Vermont valley from Bennington, through Shaftsbury, Arlington and farther north. Observations were not made with sufficient thoroughness to show conclusively whether or not outcrops of marble, or the rocks associated with it, occur within the area chiefly occupied by the Lower Cambrian series, and therefore whether actual overlap occurs as it does around Brandon, although probable overlap by thrust is suggested.

Dolomite like that associated with the marble around Brandon and farther south in Dorset was noted at Leicester Junction and at other places and the interbedded series was found a mile west of East Middlebury village along the road from that village to Middlebury. The valley quartzite, however, northwest of Lake Dunmore extends westward to a meridian a mile west of East Middlebury village, at least.

East of Lake Dunmore is a prominent scarp in the quartzite and the lake appears to lie in a structural basin. North of Lake Dunmore the place of this scarp is taken by another lower one which breaks the quartzite a mile west of Bryant Mountain. The basin in which the lake lies appears to be the counterpart of those at the south near Arlington and Manchester which are filled with drift.

Three miles northwest of East Middlebury village, and two miles from outcrops of the interbedded rocks of the Lower Cambrian series west of the village, along the road to Middlebury, are exposures of sheared, blue limestone, carrying gray, woolly patches which after a short distance are succeeded by outcrops of marble that lie about a mile southeast of Middlebury village. The relations thus far noted present a strong similarity to those found around Brandon.

In the fields a mile west of Middlebury are abundant exposures of the bluish or dove-colored rock showing the same shearing and the same gray patches that have so frequently been mentioned and which are associated with other limestones resembling the Trenton. Many ledges were examined for fossils, but nothing definite was noted. The prominent structural feature is strong shearing with easterly dip.

Two miles west of Middlebury were observed outcrops of phyllite. Some of this rock is like the light-colored phyllites seen

in the Whiting and Sudbury exposures, in texture, but darker in color. It was found along the valley of Ledge Creek. No attempt was made to trace the boundaries of this formation with adjacent rocks and no contacts were found.

West of the phyllite is a ridge known as "The Ledge." The dove-colored rock was noted here. West of "The Ledge" the surface sinks to the level of the Lemon Fair River in Weybridge. West of the Fair the surface rises very gradually to the eastern slope of Snake Mountain.

Observations near Snake and Buck mountains. In the northeastern part of Bridport the eastern slope of Snake Mountain is formed of cherry-red or brick-red quartzite which dips easterly. On the west the mountain presents a good scarp of varying altitude fronting the lowland, but at places the drift is piled rather high against it.

Along and near the east road to Addison, west of the mountain, are good exposures of the grayish-blue limestone carrying *Maclureas, Ophiletas* and other fossils.

Two miles east of Addison village, along the road to New Haven Junction, north of the mountain, were noted black shales, weathering gray, and these one-half mile farther east in an excavation beside the road one-half mile west of Otter Creek gave many graptolites, identified as *G. pristis.* Above the shales in this pit is limestone apparently lying on the shales and which in lithology resembles some of the higher Beekmantown. At the bridge across Otter Creek is dove-colored limestone which appears again northward along the road to Vergennes apparently dipping easterly. Farther north, three and a half miles south of Vergennes, the limestone dips easterly about 20° and is full of fossils, including *Maclurea magna.* The rock does not appear to be so badly sheared as is its apparent counterpart east of Snake Mountain and southeast of Middlebury.

Buck Mountain shows a conspicuous scarp on the west which is not so sharp as that of Snake Mountain.

East of the limestone at the bridge over Otter Creek, along the road from Addison village to New Haven Junction, limestone gives place to quartzite, "Red Sandrock," which forms the eastern slope of Buck Mountain and dips easterly. This gives place eastward to limestone.

Near the northern end of Buck Mountain a road crosses it. North of this road, quartzite forms the base of the eastern slope, but a short distance west up the slope it gives place to large exposures of the bluish or dove-colored rock with its gray associate and the former carries indistinct fossils. Field notes indicate that the limestone is sheared and that it continues westerly and apparently forms an anticline, for easterly dip occurs on the east and one-fourth of a mile west the dip is westerly. Northward along the strike of the westerly dip the limestone presents

an abrupt, abraded edge 500 yards south of the house at the end of the private road. About three-fourths of a mile farther north and one mile south of Vergennes, in a pit east of the road, shale appears. Here the rock has a larger exposure and is more limy than that noted farther south, north of Snake Mountain, but in general resembles that in which graptolites were found two and a half miles east of Addison village. The shales appear on a meridian intermediate between limestone outcrops farther south which suggests that they were once covered by limestone or quartzite which has been eroded. In the south wall of the pit the rocks show that the formation has been greatly crumpled.

Summary. The faulted and scarped western edge of the Green Mountain plateau continues northward from Brandon and fronts a wide Champlain lowland lying to the west. Along the eastern margin of the lowland lies a series of rocks whose basal quartzite member is like the quartzite forming the escarpments of the plateau. In the lowland and on the edge of the plateau the quartzite is overlain by a dolomite and in the lowland there is present also a series of interbedded dolomitic and quartzitic rocks like those that have been described for Brandon and areas farther south. The lowland rocks are dismembered portions of those forming the plateau. The relations in the main are like those at the south throughout the long extent through which they have been traced in the descriptions of this paper.

Although conclusive evidence from field relations examined by the writer may not be offered to show that the Lower Cambrian series at the east overlaps other rocks along a thrust plane, such as was described for Brandon, a dolomite was seen during a subsequent season at Leicester Junction, lying on the marble, and the resemblance of the former to the dolomites so frequently noted around Brandon in association with the marble was noted. It does not resemble the rocks which seem to be Chazy and its counterpart was not found west of the meridian of Middlebury village. During a subsequent season also were inspected some outcrops along the road from Leicester Junction to Whiting village which bear strong resemblance to the interbedded rocks seen northwest of Brandon village. They occur south of the road about a mile west of the Junction and the exposure is limited. In fact, drift very thoroughly hides the hard rock between Otter Creek and the brook farther west, and the exposures are not at all satisfactory for study. Two and a half miles west of the Junction, just east of the railroad track, limestone shows a puddled appearance and carries salmon-pink or buff-yellow patches of calcite like those northwest of Brandon. In Huntley's quarry at the Junction a dolomite is involved with pinkish marble and west of the quarry, at some old quarry holes, beds of ochre-yellow dolomite are involved with pinkish marble.

South of the Leicester Junction-Whiting road some of the few exposures along the road to Foster corner show the sheared blue limestone of the Sudbury exposures farther south.

If the various outcrops indicated above belong to the Lower Cambrian series they carry the margin of it west of the meridians along which the marble and its associated rocks outcrop at Leicester Junction, and southeast and northeast of Middlebury village.

At Swinington's quarry near Leicester Junction the dolomite shows a structure like that at the old Norcross quarry at South Dorset. They both offer structure to be considered in connection with the characteristic deformations of the rocks of the region. See plate XXXV.

The bluish-gray or dove-colored limestone and associated gray dolomite southeast and west of Middlebury village are regarded as the equivalents of similar rocks around Brandon and west of it. West of Middlebury they have apparently the same relations to sheared blue limestone as in eastern Sudbury and the whole series bears the same relation to the phyllite in eastern Cornwall that the calcareous rocks at the south do to the phyllite formation of the Sudbury and Orwell hills. In eastern Cornwall, in fact, the phyllite band simply interrupts at the present surface the continuity of entirely similar calcareous rocks that now lie each side of it. These calcareous rocks lie on the phyllite and are not interbedded with it. Westward in the valley of the Lemon Fair the hard rocks largely or wholly disappear from surface view and the next outcrops westward are the quartzitic rocks of the "Red Sandrock" formation on the eastern slopes of Snake Mountain. Farther north, however, on the meridians of the phyllite and the limestones west of Middlebury the "Red Sandrock" of Buck Mountain appears at the surface with every indication at its northern end that limestones similar to those lying on the phyllite west of Middlebury village also lie on it, while the quartzite on the eastern slope of Buck Mountain passes eastward beneath similar limestones. Whatever it may mean, there is a substratum to these similar limestones which shows a lateral variation within not very long distances from phyllite to quartzite.

The published descriptions show that with minor surface interruptions the quartzite of Buck Mountain connects northeasterly with similar rock in Monkton, which in turn is described as "merging" with the quartzite of the plateau. Account should be taken, of course, of the normal and other probable displacements at the east.

Snake and Buck mountains are the topographic counterparts of the interbedded quartzite and phyllites composing the Orwell hills. They also lie along practically the same meridian.

West of Snake Mountain are calcareous rocks apparently similar in important respects to those at the east, but less altered, and fossiliferous; the dove-colored rocks yield Chazy fossils.

North of Snake Mountain are black shales giving "Utica" graptolites and this rock is overlain by limestone, which is probably of Beekmantown or Chazy age. Along a meridian lying a mile to the east are dove-colored rocks which northward west of Buck Mountain give *Maclurea magna* and other Chazy fossils. And still farther north and on a meridian lying east of the Chazy outcrops are shales like those at the south carrying *Graptolithus pristis*.

There is apparently a fault in the quartzite on the north of Snake Mountain, but it is not apparent that there is any structural lateral offset. The physiographic offset between Snake and Buck mountains appears to be due to the irregular course of the displacement that bounds those eminences on the west and which north of Snake Mountain swings eastward and then again northward. There are minor scarps and surface interruptions between Snake and Buck mountains. Around Snake and Buck mountains there were not noted by the writer any places at which the quartzite and shales are in contact and only one place, as described, was seen where the shales had limestone above them. The probable relations of the quartzite, and the limestone which probably lies on it, to the "Utica" rest upon probable conditions shown elsewhere which will be described beyond.

The displacements marked by the scarps on the west of Snake and Buck mountains have been described or pictured as reverse faults by which the quartzite was elevated to its present position with respect to the surrounding rocks. They will be discussed beyond so as to show that they are probably in character, and relations to earlier thrusts, similar to those which broke the rocks along the western edge of the plateau at the east and the Orwell and Benson hills at the south.

CHITTENDEN COUNTY.

Burlington.

(Burlington topographic sheet.)

Observations near Burlington. Vergennes was the most northern point reached by the writer in the course of a trip on foot through western Vermont in the summer of 1918. There has been no opportunity since to make close field observations between the parallels of Vergennes and Burlington. Some mention may be made in the final summary of certain published accounts of the relations shown in the territory intervening. At Burlington trips were made to points along the lake shore and to the valley of the Winooski, which may be mentioned here for sake of completeness.

The celebrated Rock Point locality at Burlington should be visited by anyone who is interested in the problems of rock deformation in western Vermont. Here is exposed a relation

that is often concealed along the lake shore. The phenomenon of overthrust falls within the range of easy understanding as one surveys the sharp contact of the Cambrian sandstone on the Ordovician shale formation, and the inspection is helpful in visualizing the relations at other places where the aid of the imagination is needed more.

The massive quartzite-dolomite, "Red Sandrock," often without any marked visible internal deformation, rests on greatly crushed and crumpled, black slates and shales, with stringers and nests of quartz and calcite. The color of the quartzite varies in this vicinity; while often red it is frequently gray and brown. The shore section at Rock Point is a detached one; north and south of it the shore is in Champlain clays.

East of the lake shore the best exposures near Burlington are along the Winooski River. At the Lower Falls, red and gray quartzite in massive ledges in the stream and along the banks lie in a flattish position, dipping gently in a general easterly or northeasterly direction. East of Winooski village the gray quartzite is succeeded by limestone of uncertain age.

FRANKLIN COUNTY.

St. Albans Bay.

(St. Albans and Milton topographic sheets.)

Some observations along the lake shore south of St. Albans Bay. Some apology seems necessary for the very brief original notes offered for the country north of Burlington. A part of one rainy day was spent along the lake shore near St. Albans Bay south of Melville Landing. Heavy weather prevented much being done on the trip and illness from influenza practically closed field work for the season.

From Melville Landing southward the shore as followed for three miles towards Camp Rich in Milton is formed of "Utica" slates and shales which form low cliffs and minor headlands. The road hugs the shore for the distance mentioned and advantage has evidently been taken of the level topography in laying the road out. Back from the shore at varying distances are exposures of limestone which were not examined except as mentioned beyond. The slates were inspected casually for fossils but none was found.

About two miles north of Camp Rich, above a shore cliff of the shale and only a few rods from the shore, were noted light-colored, siliceous phyllites or slates which at once recalled the similar rocks in Whiting and Sudbury. This exposure seemed somewhat isolated and surrounded landward by limestone. Ledges of the latter occur only a few feet away from the slate, but the contact was not seen. The relations were not absolutely conclusive as to whether the limestone or the slate was superior

in position. The shore road is here a fourth of a mile from the bank. Limestone apparently continues eastward to the road and across it. East of the road a low ridge of gray, "marbly" limestone is succeeded by a fairly high escarpment of gray dolomite. From the general relations as noted here and northward, east of the shore road, it was concluded that the phyllite is beneath the limestone and that the former rests on the "Utica." The phyllite is correlated in the writer's mind with similar ones farther south in Addison County and is thought of as, in general, equivalent to the quartzite or "Red Sandrock" which farther south in Milton and Colchester comes to the shore, either resting on the "Utica" or dipping into the lake. The phyllite north of Camp Rich as just described is apparently very limited as a surface formation in the immediate vicinity of the outcrops noted. Northward towards St. Albans Bay, limestone apparently rests on the "Utica," to judge by general field relations; but both phyllite and limestone are regarded as resting by thrust on the "Utica" formation.

GRAND ISLE COUNTY.

South Hero and Grand Isle.

(Plattsburg topographic sheet.)

During the season of 1920 some examination was made of the formations on the island of Grand Isle, often in the company of the State Geologist. The geology of this interesting island has been most recently studied by Professor Perkins, whose excellent and careful descriptions will be found in his Second and Third Reports. In this paper the writer wishes to record only a few observations which bear more particularly upon the deformation of the rocks.

The surface mantle on the rocks of Grand Isle is largely composed of the deposits of an old "lake" bottom. The exposures of the hard rocks, however, are sufficiently numerous inland, even over the lowest portions, to permit an apparently fairly accurate delineation of the boundaries of the different formations; but the covering is heavy enough to conceal in most places such critical features as contacts over considerable distances.

In a general way the formations may be divided into the shale formation, which occupies the northern, eastern and southeastern portions of the island, and the limestone strata which stretch as a wide strip along the western side from its southwestern end northward two-thirds the distance across the island from south to north, and which at the north extend towards the east into the central portions. The present apparent surface distribution, in a large way, of the rocks just mentioned, in itself appears to have some structural meaning which apparently could hardly be grasped in its true signification from the study of this

island alone. Especially confusing would probably be a close age relation of some of the members of the shale-slate formation with some members of the limestone strata and an apparent transition between the two at many places, not only in lithological characters, but in the fossils as well. In addition to these features of general distribution there are some details which will be mentioned presently.

The limestone strata include the Beekmantown, as a small patch at the southern end, which is better exposed on Providence Island a mile and a half away, the Chazy, Black River and Trenton. In general as seen along the shore and also inland a short way from it the beds of these different terranes have not been greatly deformed internally. An almost continuous section in limestone extends from Phelps' Point at the southwest to Wilcox Cove along shore, and more or less widely interrupted exposures occur to the eastward a short way from the shore along an old "lake" bottom and along the old beach and some ridges that bound it on the east.

The Chazy rocks are usually impressive in their massiveness. Some of the beds are several feet thick; in one case a bed is as much as 20 feet through. These strata are prevailingly quite flat in position along shore, and so far as examined are free of pronounced internal deformation, although they show more evidence of it inland so far as the more limited exposures permit observation.

The Black River beds are limited. They too are somewhat massive, but less so than the Chazy rocks. They might be considered as somewhat intermediate in this respect between the Chazy and the Trenton. Along shore these beds are also prevailingly almost flat in position. They are very smoothly and symmetrically jointed as a rule. An occasional outcrop of rock with some characters of the Black River, but much crushed and filled with veins of calcite, occurs near the west shore; but a consideration of general relations makes it seem doubtful if such rock is in place.

By far the larger part of the limestone as mapped for the present surface belongs to what is called Trenton, and which probably is Trenton, but perhaps not all there is on the island that should be included in this terrane. Professor Perkins has been impressed with the Trenton or transitional character of some members of the shale-slate formation and has been at work on the problem of a clearer separation of the Trenton from the so-called "Utica" of the island. From what will be indicated beyond it may appear that structural features among some of these rocks will have to be considered in working out their age and other relations.

The Trenton rocks that are readily recognized and have been mapped as such have, like the Black River and Chazy, where

they occur along shore a nearly horizontal position. A fine section is exposed from Rockwell Bay northward, in which there appears to be only gentle but variable inclination of the beds. The exposed portion of the stratum is composed of limestone beds of varying thickness, ranging from 2 through 4 or 6 to 8 or 10 inches with intercalated shaly layers. The rocks in their dark gray and somewhat monotonous appearance throughout are in contrast with the dense and more heavily-bedded Black River and the massive and often more distinctly marked Chazy.

Deformation of the Trenton beds, including visible shearing within them, is found in the shore section and now and then a small fold or buckle appears which sometimes appears to be associated with a fault displacement. In one case the latter appeared to be a tension fault; at another place, near Wilcox Cove, there was suggestion of thrusting and therefore of compression. On the whole, however, along shore there is less evidence within the various limestones of the action of compressing forces upon them than farther east. There is some evidence of normal faulting across the general strike of the rocks, both within formations and between them, and some of these are apparently marked by shore indentations at the present time, as well as by juxtaposition of rocks of different ages. How far most of these displacements may run inland it is difficult to find out.

It has been assumed and would probably by many observers be assumed that these various limestone beds and formations have at the present time their original stratigraphic interrelations and primary geological sequence, and that they are probably near the place of their deposition; that, in other words, they have not been greatly disturbed from the place where they were laid down, though bearing some evidence of deformation.

The careful systematic examination which would be necessary to show it was not made to find out to what extent, if any, the primary interrelations of the rocks of different ages which these limestones represent, may have been changed by the action of thrusts; but in addition to the insignificant disturbances which have been mentioned, effects distinctly to be attributed to the action of compression were observed in the limestones at other places on the island.

Along a ridge about one-half mile east of the west shore and east of Sawyer's Bay, and eastward from this ridge in more scattered exposures, beds of Trenton limestone give satisfactory evidence of internal deformation, not only in their sheared structure, but in the compression, distortion, fragmentation, or obliteration of their fossils. Minor buckling may be seen and an easterly dip due to shearing can be readily distinguished from that of stratification. Some of the fragmentation of fossils may have occurred during or prior to deposition; but in the field it is possible within short distances across the strike, and sometimes apparently

along the strike, to pass from one ledge with excellently preserved fossils, such as *Bellerophon,* to other ledges in which, at the distance of only a few hundred yards at the most, alteration will vary from compression, as shown by a flattened Bellerophon, nearly to obliteration. Account is taken in this statement of differences in fossil contents due to natural variation in passing from bed to bed across the strike.

Observations seemed to indicate that in the Trenton beds, because of their more thinly-bedded character, deformation due to buckling and crushing, and probably shearing, found expression more readily than in the more massive Black River and Chazy. It hardly needs more than a casual inspection of the limestone rocks as one goes east from the lake towards their eastern edge to discern the evidence of the greater disturbance and deformation which they show over those along the lake at the west. Along their eastern margin some of them are clearly crushed and carry many calcite veins.

The limestone formations whose deformational features have just been discussed are those which may in the field be separated clearly from those which have some similar lithologic and structural characters, but which are in more intimate major structural association with the shale-slate formation. Along the lake shore at places between Rockwell Bay and Wilcox Cove beds of not appreciably deformed rocks of probable Trenton age pass into other apparent Trenton rocks which are rather strongly sheared, and between these and other rocks which have been called "Utica" there is sometimes difficulty in drawing any decided lithological distinction.

The so-called "Utica" slates and included limestones, perhaps together with some Trenton rocks, may apparently as a formation be differentiated somewhat sharply from the limestone strata which border the lake, as just described, on the basis of the deformation which it has suffered. In general, these rocks present much the same aspect with respect to deformation wherever observed. Under severe compression the beds of the shale-slate formation have not only been folded and tilted, but apparently because of pronounced difference in behavior of beds of different thickness and strength under stress of pressure and probably also load, there has been frequent rupture with much crushing and frequent movement of one part of the mass over another part, producing great confusion. An exposure of great interest as showing this behavior of the slate formation is to be seen in the cliffs south of the Grand Isle end of Sand Bar Bridge, and which is pictured in the Third Report. In lithological and deformational aspects the members of this formation are like those along the shore of the mainland south of St. Albans Bay and at Burlington and in essentials like those farther south in Addison County. The lithological differences and resemblances among the dif-

ferent slates and shales through the distances separating the localities just mentioned are of the same order and character as those which appear in comparing the slates of western Vermont with those of some parts of the Hudson valley.

Interpretation. In the course of the writer's examination of Grand Isle the question arose very early in his mind as to what is the present structural relation which the limestones have to the slates. Search did not show any of the limestones resting on the slates. So far as the writer's observations have gone, and also the descriptions of others, it appears that the structure of the island as a whole is best explained by the relations shown at the east on the mainland and at other places in western Vermont which have been described in this paper.

In the first place, one notes the relatively great deformation of the shale-slate formation already referred to and the contrast which it bears to the limestone strata viewed as a mass. The contrast recalls the relations on the mainland where a dolomite-quartzite showing little visible internal deformation rests on greatly crumpled slates and shales in all essential respects like those of Grand Isle only a few miles to the west. The slates of the mainland having the inferior position to older rocks that has been noted at so many places, but in this connection, especially along the lake shore from St. Albans Bay to Burlington, undoubtedly once had connection across what is now the lake surface between the mainland and Grand Isle with the slates of the latter. Did the Cambrian quartzite ride over the slates, or rather did the thrust plane along which it was driven cut through the slate formation above the limestones now exposed at the surface on Grand Isle, or did it cut through it along what is the plane of contact of these limestones on the slates? In other words, do the limestones of Grand Isle structurally lie below the "Utica" of the island or above it? If above it, they lie unconformably along a thrust plane and are not in their original position. The considerations offered all suppose the slates to be younger than the limestones. On such a supposition as overthrust there probably will not be in most cases, of course, actual transition from undeformed Trenton limestone into deformed "Utica" slate or limestone. There might, however, be transition from sheared Trenton limestone into continuous, unsheared limestone, but all within the mass that had been moved. The idea of overthrust does not preclude the inclusion of Trenton rocks in the "Utica," but such rocks would presumably have to be thought of as having once been separated from the undeformed Trenton rocks by a greater or less interval.

In connection with the idea of overthrust the question of the relations of the limestone strata of Grand Isle to the quartzite on the mainland calls for consideration. A better knowledge than the writer has of what lies on the quartzite east of the lake

might help in answering this question. Published accounts are not conclusive. Conditions farther south that have been examined may give some suggestions.

Did the quartzite which now lies on the slate formation along the mainland at Malletts Bay and Burlington once extend over both the slates and the limestones of Grand Isle? Or did its extension westward by thrust stop short of Grand Isle? Its absence west of the mainland is not conclusive, but is suggestive. It would seem that if this durable formation once extended any distance west of the eastern shore of the lake some remnant of it would be preserved. In this connection may be recalled the apparent contact of limestone on the slates around St. Albans Bay with apparently no quartzite or phyllite intervening, and other places southward where either some phyllite, or slate, or quartzite, lies between limestone and the "Utica." Again may be noticed the eastward extension of the lake surface to form St. Albans Bay where apparently only limestone rests on the slate formation. It would appear, even from the few observations made by the writer in northern Vermont, that either limestone, or quartzite, or phyllite may rest on the "Utica," presumably by thrust, along the mainland. In view of this probability it is not difficult to imagine the limestones of Grand Isle as lying on the slate-shale formation by thrust.

In the areas farther south that have been described, it will be recalled that along the lake region it is some member of the limestone that lies on the "Utica" and that at only one or two places of obscure relations is there suggestion of visible contact of any member of the quartzite-phyllite formation on terrigenous rocks of younger age.

The correlation and unification of the phenomena of these various localities will have to be undertaken in the closing summary.

At places on Grand Isle the Chazy and apparently the Black River are shown to have such relations to the slates, when mapped and when inspected in the field, that it is difficult to draw any other conclusion than that the two are in contact. At other places it is the Trenton that is or appears to be in contact with the slates. Judging again by conditions as shown farther south, some of the relations of limestone to slate on Grand Isle may be the results of displacements due to normal faulting; but all of them apparently may hardly be explained on such a basis. There is nothing to suggest that the limestones have been completely inverted; they retain at least their depositional attitude. When one finds a mass of Chazy limestone surrounded on three sides by the slate formation and remembers that the latter is unquestionably the younger rock, two possible explanations suggest themselves; either younger rock has simply been dropped by normal faulting so as to surround the older rock, partly by slates perhaps

and partly by younger limestone, as is the apparent case north of Keeler Bay; or the older rock has been thrust on the younger strata. The first hypothesis is entirely adequate to explain the present relations, if perhaps we recognize the possibility of differential faulting, for there is apparently nothing in the interrelations of the different limestone strata which opposes such a view. On either view the limestones are presumably present at depth, but in one case the limestones are different at depth from those at the surface with respect to their original relations to the slates of the island and in the other case the rocks at the present surface and at depth have presumably simply slipped by one another along planes of normal faulting. The latter view would of course have to assume some disturbance as the result of compression in order to account for the features shown by the various rocks, but might in the minds of some, not appear inconsistent with the contrasts exhibited by the two principal formations of the island with respect to their deformation. Such a view, however, does not seem to take sufficiently into account the obvious thrust deformations of the region of which the island is a part. Whether we assume or not that the big mass of Trenton rocks in the western part of the island is underlain by Chazy beds, the explanation of relations seems to be possible on the basis of thrusting. Probably we should have to take into account that the map to show the distribution of the formations is not absolutely accurate, although as much so as conditions at the present time allow in view of the surface covering and the non-committal or doubtful character of isolated and small outcrops. Where the present conditions suggest Trenton in contact with slates may not be really the case; but even if it should be normal faulting subsequent to other deformation might readily account for such conditions, although normal faulting is perhaps not necessary to explain them.

If on the mainland it is quartzite-dolomite that rests by thrust on the slate formation there appear at least two possible ways to account for the relations on Grand Isle and of Grand Isle to the mainland by thrusting:

1. Prior to the major thrust, as it may perhaps be called, that carried the quartzite over on the "Utica," as now shown along the mainland, there was reverse faulting and minor thrusting by which the limestones lying east of what is now Grand Isle were broken, perhaps because of the massive character of the Beekmantown-Chazy strata, and thrust up and over the "Utica." In this deformation the slates were tilted and overturned. As the heavy limestone strata rode over them they were further jammed beneath the load and by the drag and often broken and mashed. The limestones themselves were broken and moved more or less against each other. At this time were formed the deformational features which they show. Subsequently there

occurred some normal faulting, perhaps differential in the same episode, and as a deformation perhaps repeated. Before the normal fault displacements presumably thrusting had ceased. Before it had ceased perhaps the stresses which had been only partially eased by the reverse faulting and minor thrusting just referred to produced a great thrust that carried the basal Cambrian up through the "Utica" and drove the former westward over the younger rocks, and over those which now form Grand Isle. But it has already been remarked that if the quartzite once extended very much farther west of its present edge along the shore of the mainland it seems somewhat remarkable that some remnant of its westward extension has not been preserved, unless the mainland is a downfaulted block with reference to the lake region which does not seem probable. According to this postulate, however, it is not necessary to assume that the quartzite once covered what is now Grand Isle.

2. The limestone strata of Grand Isle once belonged to a region that lay eastward from Grand Isle and the "Utica" slate formation on it, one may not say how far. They may have had a relation to the quartzite-phyllite formation entirely similar to that now shown by the limestones which have been described as lying on the phyllite formation at the south in Benson, Orwell, Sudbury and other parts of Addison County. At the time this region was undergoing the compression that produced the various thrusts which may now be seen, there was at first ease of stress by shearing and minor faulting and thrusting. Then came a great thrust, widely extended, deep and powerful, and strongly resisted by the combined masses of the quartzite-phyllite formation and the heavy strata of limestone which lay on the former. The great thrust cut through the various rocks along an irregular plane that often intersected the quartzite, but often also passed from that formation into the overlying limestone strata and cut irregularly through them. As this rupture developed, the mass above rode over the mass below. Sometimes the quartzite and sometimes the limestone was brought to rest upon the slate. When the thrust left the quartzite-phyllite formation and cut into the limestone the former was left at depth west of the presumable line of emergence of the thrust at its surface. Not only would such a thrust plane as has been postulated be very irregular as a plane, but the line at which it cut the surface originally and its trace after erosion would probably be very irregular and sinuous. It is even conceivable that such a plane would have cut through a great thickness of Beekmantown, Chazy and Trenton beds in such a way as to carry Beekmantown here, Chazy there and Trenton at still other places on the "Utica." After, and perhaps a long time after, such thrusting as has just been supposed had ceased, there would have occurred normal faulting. The laterally disturbed masses were now chopped more or less

vertically and displaced. Some of the relations on the island now existing or apparent, might thus be explained. By such an hypothesis of thrusting as just developed, the quartzite probably never lay over what is now Grand Isle, although it may once have overlain a part of what is now lake between the islands

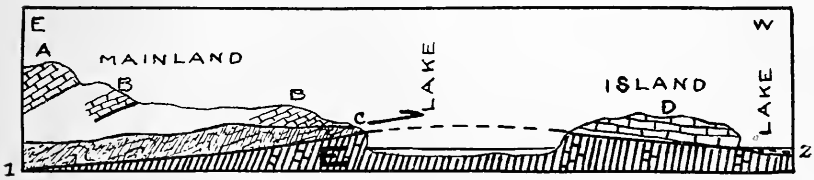


FIGURE 21. A generalized section to show the writer's interpretation of the present relations of formations along the eastern shore of Lake Champlain north of Burlington. The relations shown on the mainland are drawn from studies near St. Albans Bay. A, gray dolomite; B, gray, "marbly" limestone; C, light-colored, slaty phyllite (Lower Cambrian); D, limestone capping an island and resting by thrust on folded "Utica" slate, E. 1-2 thrust plane.

and the mainland. At St. Albans Bay apparently we have the thrust plane cutting through the limestone except at certain places where a bit of the phyllite was caught beneath it; but farther south at Malletts Bay and Burlington, the plane passed well down in quartzite and opposite here the quartzite conceivably once extended farther westward. The region now represented by the lake has been excavated in "Utica" shale and slate after the removal of overthrust rock that was partly quartzite and partly limestone. The writer has not had opportunity to inspect the mainland on the New York side in a critical way; but certain relations seen farther south, near Benson Landing, suggest that part of an overthrust mass of Ordovician limestone now rests against the Adirondack mass north of Putnam Station, and one wonders how far overthrust may have affected the New York side. According to this view of the relations at Grand Isle the limestones there could hardly have been exposed to view by erosion of overlying slate; but presumably limestones similar to those at the surface exist at depth below Grand Isle.

That the various considerations just offered are more than speculations is proved by overthrust farther south. Practically on the meridian of Grand Isle and 60 miles south of it along the east shore of Lake Champlain in Orwell, as has been described, we find the "Utica" formation and in some cases, apparently, Black River and Trenton, rocks, overridden by members of the Beekmantown formation and perhaps older beds which also have been cut through in such a way as now to carry one horizon and now another over on the slates. The erosion of the overthrust limestones at places in western Orwell has exposed the "Utica" slates which are sometimes inundated and sometimes not. Here again the quartzite-phyllite formation lies to the east and over it the

limestones of western Orwell seem to pass eastward, as has been described. Similar relations are shown in Shoreham, but in this township, and in Whiting on the east, the limestones have been better preserved. The quartzite-phyllite formation emerges at the present surface only as a low ridge through Whiting. At the west the "Potsdam" of Shoreham village fronts a wide lowland partly swamp and partly hills of slate. Here we have in process of formation the kind of hard rock surface and topography which the unglaciated bottom of the lake would present, and it becomes apparent that the lowest portion of the Champlain lowland is the surface of the rock bottom of the greatest depth of the lake.

The various detached masses of limestone found now at various places in the region of the lake seem to be not simple erosion inliers of rock substantially resting where it was formed, but rather thrust-erosion inliers of rocks now more or less removed from the places of their deposition. Whether it is likely that these displaced rocks have been moved more than once for any distance from their original sites may be discussed in the final summary.

Mention has been made of probable normal faults cutting across the strike of the rocks of Grand Isle. These undoubtedly pass down into the slate formation. Numerous dikes of igneous rocks cut through the slates and limestones along the shore and inland. These dikes usually show no evidence of great disturbance after their formation. They were formed after the limestones came to have their present relations to the slates and probably after or during the subsequent period of normal faulting. In the cliff south of the Grand Isle end of Sand Bar Bridge there is a dike that gives some suggestion that it has been disturbed, but not greatly. Perhaps it would be possible to explain its features as due to the character of the original fissure; in the limestones, while there is some offsetting here and there, it is evidently due to the dike rocks following a previous small lateral displacement. Igneous intrusion in the form of dikes is widespread on the island, and on the mainland even southward to and in the Taconic region.

GENERAL SUMMARY.

The studies offered in the preceding pages were begun with the definite idea of trying to get some light on the plan of structure of the rocks of western Vermont. As details accumulated it became apparent that many different areas presented similar phenomena involving similar rocks and the search began for some principle that would unify the various features of the field relations and explain the apparent anomalies.

Suggestions have been offered in the preceding discussion at several places as to interpretations that might be put upon

field relations; but it has been the writer's experience that hardly a single area sufficed to explain completely its own structural features. At several places also certain questions which the field relations raised have been formulated and the statement made that answers to them might later be attempted.

The preceding descriptions have shown the confusion that prevails in the field, but at the same time have tried to make it plain that when the surfaces of different areas are carefully compared there is at many places over a wide region much apparent uniformity in the relation which certain rocks bear to each other when such differences as metamorphism and present condition of erosion are taken into account. Careful examination also brings out the existence of certain kinds of deformation in the rocks of the region which having once been seen are readily recognized at many places and soon impress one as being characteristic. The resemblances that appear from place to place grow upon one and the differences stand out less prominently until the time comes when it seems possible to discern some order in the midst of the confusion.

The first working hypothesis which suggests itself is that the key to the present relations is that of secondary deformation of the rocks. They have been profoundly disturbed. Underneath their present static relations and immobility it seems possible in imagination to see them once more in action. While the changes which have been wrought throughout the long time that has doubtless elapsed since the rocks underwent their major deformations have greatly dimmed the complete picture, and the light from scattered localities gives only an uncertain illumination of some features, encouragement is experienced in the fact that the main outlines come out with increasing sharpness as new areas are examined.

In presenting this summary and in inventing hypotheses by which to try and explain the various structural features and the history of the region as a whole, there are several apparently important field relations that should be kept in mind more particularly to bring out unity of structure. With these it would seem the minor differences must be reconciled.

1. The great north and south extent along the western edge of the Green Mountain plateau and eastern portion of the Vermont valley in Vermont, from Pownal to Middlebury and beyond, of a similar series of rocks comprising conformable, thick-bedded and thin-bedded quartzites and interbedded schists at the base, followed by dolomites and interbedded dolomites and quartzites.

2. The conformability, as shown at Bennington, of the different rocks named in 1 in the order of (a) quartzite-schist formation; (b) dolomite or dolomitic limestone; (c) interbedded dolomites and quartzites.

3. The occurrence of this series at the present time chiefly in the areas mentioned in (1) and the predominance of the upper members in the valley and lowland, where they appear sometimes in conformable relation with the quartzite member of the series and where sometimes the interbedded rocks rest directly on marble, or directly on quartzite, and apparently at some places on an interbedded quartzite-schist formation. The frequent occurrence of a dolomite resting on the marble or involved with it, which dolomite differs from other dolomite with which it is in frequent proximate field association and seems to belong to the same general formation to which the quartzite and interbedded dolomites and quartzites belong.

4. The present absence of this series just described, in its completeness, west of the Vermont valley.

5. The wide distribution west of the Vermont valley, including parts at least of the main Taconic range, of a terrigenous formation made up of black phyllites or schists, lighter-colored, fissile or slaty phyllites, and more or less massive quartzite which are rather plainly interstratified, as shown in surface sections at numerous places from the latitude of Pownal to that of Sudbury and which can be discerned in fault scarps at places west of the range in the Taconic hills.

6. The striking similarity among black phyllites and other members of this terrigenous formation at most places over the region of its present distribution, with certain variations appearing on account of greater metamorphism in some areas. The close geographical and geological association which this formation has with the quartzite-dolomite series described above and the similar north and south extension of the two in this association at the east along the region of the Vermont valley.

7. The practical restriction of the outcrops of the marble formation to the region of the Vermont valley, or to the incisions along the eastern border of the Taconic range, or to the eastern part of the Champlain lowland; and the exposure by erosion of patches, belts, or other outcrops of the marble from beneath the calcareous members of the quartzite-dolomite series described above (3), and apparently also from beneath masses of terrigenous rocks having the interbedded structure and composition mentioned above (5).

8. The probable Lower Cambrian age of the quartzite-dolomite series on the bases of fossils found in the quartzite and at some places in the calcareous members, in connection with the conformability shown by the members of the series.

9. The clearly disturbed condition through compression of the Lower Cambrian series along the western margin of the plateau, involving displacements of one part in relation to another part of the series and the displacement of the whole series or parts of it by overlap on other rocks; the former to be observed

all along the western edge of the plateau and the latter to be noted at many places, at some more clearly than at others.

10. The practical impossibility of separating on any basis, except somewhat different mineralogical composition clearly due to metamorphic changes, rocks found on the edge of the plateau and others found in the Taconic range and its physiographic outliers and also in the hills of southwestern Brandon, and of Sudbury, Orwell, Benson, Hubbardton, Pownal, Bennington, Shaftsbury, Pawlet, Rupert, and other townships, some of which have been mapped as "Berkshire Schist" and some as "Cambrian." The wide distribution at the present erosion surface of all the characteristic members of this terrigenous formation from Pownal to Sudbury and possibly also to the northern part of the State, although the writer's examination of the region along the lake north of Burlington gave only the quartzite and the lighter-colored phyllites, and between Whiting and Burlington only the quartzite ("Red Sandrock").

11. The apparent wide distribution, with interruptions over large areas clearly due in part to erosion and probably in part to previous disturbances which affected the ways in which erosion could work, of Ordovician limestones and their metamorphosed derivatives on the terrigenous formation which has been described, found in Whiting, Sudbury, Brandon, Orwell, Benson, West Haven, Hubbardton, Danby, Tinmouth, Rupert, Shaftsbury, and also at the north near St. Albans. The occurrence of similar limestones on the quartzite, or "Red Sandrock," of Snake and Buck mountains, and in their vicinity. The greater continuity at the present surface of the Ordovician calcareous rocks in Shoreham, Whiting, northern Sudbury and Orwell, and the much more fragmentary condition of the same rocks at the south in the Taconic hills.

13. The impossibility of assigning age to the terrigenous rock on the basis of the limestone associated with it in all the places examined.

14. The overlap in some places of quartzite of Lower Cambrian age (at and north of Burlington) and at other places of Ordovician limestones, like those which rest on the terrigenous rocks, including the quartzite, on the slates and shales of the so-called "Utica" formation, to be seen at various places along or near the eastern shore of Lake Champlain.

15. Evidence of repeated normal and reverse faulting in the quartzite-dolomite series, the latter sometimes causing the quartzite, sometimes phyllite to rest against the dolomite or against the interbedded members, various aspects of which faulting may be seen at different places from Bennington to Salisbury, along the eastern portion of the Vermont valley.

16. Evidence of repeated reverse faulting and of normal faulting in the overlapping Ordovician strata near the lake, to be seen in Shoreham and Orwell townships and at other places.

17. Evidence of disturbance by normal faulting, and probably also by reverse faulting, of the quartzite-phyllite formation among the Taconic hills.

18. Evidence of internal deformation by strong shearing of the calcareous rocks lying on the the terrigenous rocks which increases somewhat gradually as one goes eastward from the lake region.

19. The highly-metamorphosed character of the marble at the east.

20. The more schistose condition of the rocks of the main Taconic range.

21. The relatively unaltered character in most cases of the rocks near the lake.

22. Absence of recognizable Beekmantown east of the immediate vicinity of the lake.

One of the first difficulties that was encountered in applying any hypothesis to explain present structure as a result of deformation was that of arriving at a feeling of certainty as to the age of the terrigenous formation with which the fossiliferous Chazy-Trenton limestones are so frequently associated and in such apparent relations as to leave no doubt of the superjacent position of the limestones with respect to the terrigenous rocks. Some of these terrigenous rocks have been called Ordovician and and others Cambrian in areas in which the writer was unable to see a valid distinction. The writer has satisfied himself on the point that the age of the terrigenous rock cannot always be told from the limestone associated with it—it may be in some cases apparently (Cambrian); but if this is the fact it leaves the age of quartzite-phyllite formation as a whole still a question. Especially should it be noted that the presence of Ordovician limestone with phyllite is not indicative of a similar age for the latter in any cases which the writer has examined. The limestone has the character of an overlapping formation on the terrigenous mass. The next difficulty in applying an hypothesis is to get the limestone on the terrigenous formation. How did it come there? In trying to answer this question another difficulty appears. The writer was unable to find any visible contacts of limestone on the quartzite or phyllite. In southern Shaftsbury the two are very near at the present surface and the limestone here is greatly mashed and broken, affording a suggestion that it was thrust on the phyllite; but the field relation is not conclusive. In other words, there is nothing to show that the limestone might not have been deposited on the phyllite, or at least on contiguous phyllite, and have been slightly disturbed later, or that it must have come to its present position from some more or less remote place. In other places the two rocks are near together, but the question of whether the apparent overlap is one of deposition or one of thrust apparently may not be positively settled by the contact relations,

although it has not proved possible to find any rock that might be thought of as representing the shore accumulation along the transgressing strand line of a sea advancing upon terrigenous rock. If the overlap is one of depositon it would seem that the limestone was probably laid down upon the terrigenous formation without definite and continuous basal overlapping member.

It would probably be argued that the fact of a subjacent position for the terrigenous formation with respect to Ordovician limestones is not conclusive evidence of its greater age, in a region in which thrust deformation is regarded as the key to the structure. This probably must be admitted. What is the probability as one views the region as a whole?

The Brandon-Sudbury-Orwell region is one of great interest in connection with the question of the relation of quartzite-phyllite formation to the Ordovician limestones. As has been described, the terrigenous rocks pass beneath the limestones northward in Orwell, and also in Sudbury, except for a narrow ridge that passes northward through Whiting to Weybridge. Little doubt remains that the extensive areas of limestone north of Orwell and Sudbury rest on the northward continuation beneath them of the terrigenous rocks of the hills at the south. The latter rocks also, except for normal faulting, pass beneath the marbles and their associated rocks in Brandon and appear again east of Brandon village. At this place the intimate association which they have with Lower Cambrian rocks makes the presumption of a similar age very strong.

The quartzite of Snake and Buck mountains apparently has the same relation to the Ordovician limestones that the phyllites of Whiting have and the quartzite joins northeastward with unimportant interruptions at the surface through Monkton with the rocks of the plateau, and southward after a more extensive surface interruption under the limestones with the quartzite-phyllite hills of Orwell. Through the quartzite of Charlotte and Shelburne and northward, the southern quartzite joins with that north of Burlington which carries Lower Cambrian fossils. Southward the hills of Orwell join with similar rocks that carry Lower Cambrian fossils. It would certainly seem that from surface continuity, or what amounts practically to it, since the fact of similar limestone resting on the different terrigenous rocks is apparent, the probability of the Lower Cambrian age of the quartzite-phyllite formation underlying the limestones of Benson, Orwell, Sudbury, Brandon, Whiting, and probably even Bennington and Shaftsbury, is strongly indicated, as well as the equivalence of the quartzite ("Red Sandrock") farther north to the rocks of the Taconic hills. The case would be stronger if depositional overlap of the limestones could be proved or shown to be very probable. It is hard to prove the point. In Orwell and Benson the limestones have unquestionably been greatly disturbed and per-

haps moved some distance from the east, if the contrast which they exhibit with the rocks of the lake region that have been overridden means anything in this connection; but they do not give an impression that is at all conclusive of having been transported from a distance and superposed on the terrigenous rocks on which they lie. If the point of the former widespread covering of the terrigenous rocks by the limestones be accepted as probable, then there is involved a long distance from east to west for these limestones to have been moved bodily across it over the rocks on which they now lie, although it is quite conceivable that they could have been disturbed from their original positions and probably were. It would appear more probable from the appearance which they now present that if they had a movement of translation from the east it was one in which the mass beneath participated; that, in other words, they really "rode" along the thrust plane on a mass of terrigenous rock that transported them. From all the viewpoints that the writer could utilize after a careful field study, it appears to him quite as if not more probable that the limestones were deposited on the terrigenous rocks. All the field relations suggest such a history rather than that they have come to be distributed on the quartzite-phyllite formation by thrust. On this view then the latter formation is older than the limestones and if it may be made to appear extremely probable that there is unity in the terrigenous formation over all the areas where it shows essentially the same characters, except perhaps for difference in metamorphism, then the principle of thrust as the key to structure in the presence of what may be actually seen of overlap in the region seems to apply. Some applications of it have already been made without, however, stating much about the probable relative age of the terrigenous rocks, except that they had suggestive association with the Lower Cambrian rocks at the east and that they seemed unquestionably to be normally beneath the limestones, including the marble.

In connection with the discussion or argument just given it should be remembered that on previous pages it has been contended that there is nothing which the writer has been able to see in the terrigenous rocks of the Orwell-Sudbury hills that supports the idea that two terranes are there represented. The rocks seem to compose a formational unit. The question is, What is the age of the unit? Whether one regards it as Cambrian or as Ordovician, the problem remains of accounting for the superior position of the limestones. Accordingly, the field relations were considered from the point of view of any of the terrigenous rocks being of Ordovician age to see if the principle of thrust which has to be recognized could be applied on that basis.

At this point it seems advisable to call attention again to one other relation which, in the writer's opinion, argues against the terrigenous rocks under discussion being younger than the lime-

stones, including the marbles. Over the extensive limestone areas north of Brandon, Sudbury and Orwell we do not find any schist above the limestone. The strongest argument for the younger age of the schist appears to be its superior position at places farther south. This relation has already been discussed.

The idea that any of the terrigenous rocks under discussion are of Ordovician age assumes that the limestones are in general older than such terrigenous rocks and that the latter represent changed conditions of deposition in a sea which first laid down the limestones on an older base, conformably or unconformably. How could the conditions have permitted change from limestone to sand and mud rocks so that now in what is the Taconic range the limestones could have a covering of younger schist and so that conditions elsewhere in the vicinity, such as north of the range, could be as they now are? It is still conceivable, if Ordovician limestones were succeeded and covered by terrigenous deposits, that during a period of compression and thrust, Cambrian rocks could have been brought to lie on the Ordovician schists, while the Cambrian rocks passed under the limestone at depth.

If the schist capping Mt. Anthony in Bennington and Dorset Mountain and the ridge in between be regarded as of Ordovician age, passing by resemblances which much of this schist shows, except for metamorphism to rocks that have been shown as Cambrian on maps which represent the schist as Ordovician, many of the field relations are apparently not impossible of explanation while allowing the presence of deformation of the region by thrusts.

One may first imagine an eastward transgression of an Ordovician sea probably over an eroded Cambrian floor with deposition of limestone. If after the deposition of a certain amount of limestone an elevation should have occurred landward, it is possible to imagine that terrigenous deposits would have been carried westward out over the limestone which had been overlapping the older land. Deposition of limestone would have been halted landward but might have continued at the west and at other places, so to speak, while the muds and sands under the new conditions were making at places at the east. It is of course possible to imagine that these terrigenous rocks were restricted in their distribution and were not laid down everywhere along the changing strand. While some effort is required to imagine different conditions of deposition in such close proximity as to give originally the same abrupt passage from schist to limestone that is now to be seen at the northern end of the Taconic range, it is not inconceivable. In some way, according to the terms so far given of this hypothesis, the absence of the schists over the marbles and limestones at the north must be explained, it being assumed that the limestones at the north and those underlying the schist at the south are essentially the same and that both rest on

a similar base. We may further imagine that the westward distribution by seaward overlap of muds and sands was restricted, perhaps in some places more than others, in its extent and that at the west these deposits graded laterally into more limy muds which graded downward into Trenton and upward into the so-called "Utica." We may imagine that at certain places the deposition of limestone continued practically during the whole time that the schists were making at other places, or that at places the limestones were succeeded by other deposits which were of such character that they could be easily eroded and therefore do not now appear above the limestone, as north of the Taconic range for instance.

The hypothesis just considered is in reality the theoretical extension of another involving other field relations and considerations, more especially the occurrence of essentially equivalent limestone strata lying on a terrigenous mass, composed everywhere of parts indistinguishable in one place from those of another, and which seems to be a formational unit, and which occurrence, as discussed above, seems to be due to the deposition during the Ordovician period, and perhaps the latter part of the Cambrian period, of the limestones of those periods on the mass of terrigenous material which now underlies the limestones. The field relations indicate unconformity of contact although actual contact was not found.

If now we take such evidence as we have of the age of the terrigenous substratum, some of which was given above, and regard it as of probable Cambrian age and probably largely Lower Cambrian, from what we know of the geology of surrounding regions as well as that of western Vermont itself, we may formulate more definitely another hypothesis to explain certain primary relations which preceded the disturbance of the region by great thrusts.

We may imagine the Paleozoic history of the region to have begun with the deposition of extensive masses of terrigenous materials marked by a thick sandstone at the base overlapping from the west on an older land north and south all along through what is now western Vermont and certainly also beyond its confines. As the sea deepened offshore, muds mingled with the sands until a great thickness was accumulated. Oscillations of level or other conditions, perhaps a combination, finally produced a mass of interstratified mud and sand. We may further imagine that there was lateral variation in these terrigenous deposits. Possibly where rivers flowed into the sea the sands were carried farther offshore and formed deltas between deposits of finer materials extending in either direction, north and south. On these deltas the ebb tides and periodic diminution of river floods exposed the sands to the weather and the oxidizing agencies produced the red color now marked by certain members of these

rocks on which the limestones now seem to lie. Finally, conditions would have permitted the deposition of the dolomitic limestones and interbedded dolomites and quartzites so widely present north and south in association with the quartzite-schist series. The hypothesis as thus far developed does not assume that the present geographical relations between the rocks of the Taconic region that are being regarded as Lower Cambrian and the Lower Cambrian rocks along the western edge of the plateau and in the Vermont valley was the one which obtained when these respective rocks were forming; but on the contrary recognizes that they are now separated by thrusts. Nevertheless, the calcareous rocks of the Lower Cambrian series were probably once present over the Lower Cambrian terrigenous rocks of the Taconic hills.

After deposition of Cambrian sediments had continued for a time, perhaps for Middle and part or all of Upper Cambrian time as well as during the Lower Cambrian period, a disturbance may be thought of as having folded or otherwise deformed the Cambrian beds and raised them above the sea. Erosion would have followed and a considerable but unknown mass of rocks presumably would have been removed, exposing the Lower Cambrian rocks. The changes which the Cambrian rocks underwent during this disturbance could be thought of as having produced some of the differences now apparent between them and the limestones which rest on them at many places. It is noticeable, from east to west, that the terrigenous rocks on which the limestones lie are more uniformly altered than are the limestones; they present less variation in metamorphism over the same areas.

Finally came a submergence of this denuded Cambrian surface and the deposition of a series of calcareous rocks, one can hardly say at just what time because the bottom of series is not now present in western Vermont, as the oldest Ordovician limestone or sandstone usually rests by thrust on much younger strata. One cannot say what may be present at depth underneath a probably great thickness of Ordovician rocks in the lake region which have been overridden by great masses of other rocks, including some Ordovician. The hypothesis of Ordovician deposition that is being developed is in fact erected on the basis of the overriding mass, in largest part.

Near the lake the great thrust plane along which were carried the rocks from the east over on those at the west, sheared away from the terrigenous rock into and through various Ordovician horizons, but apparently through nothing older than the so-called "Potsdam" which has been described.

The deposition of the limestones apparently proceeded by overlap eastward, laying down first, at the west, the Beekmantown and by progressive advance farther east some Chazy and Trenton. What may have come above the limestones at the east has already been discussed. At the west we have evidence that the Trenton was followed by the "Utica," but this rock apparently

does not now appear east of the erosion margin of the great thrust except from beneath by exposure from erosion, as south of Mt. Philo in Ferrisburg and Charlotte.

Such an hypothesis seems to offer a ready and simple explanation of the occurrence of Chazy-Trenton beds apparently resting directly on the terrigenous formation in Orwell, Sudbury and Benson, if the latter formation is the Cambrian. It also permits the interpretation that the fragmentary areas of Ordovician limestone in the Taconic hills are erosion outliers resting unconformably upon the rocks beneath. The hypothesis does not necessarily call for the interpretation of schist now resting on the limestone, or marble, as younger, in view of the possibilities of modifications by thrust deformation. One thing that seems to support the idea of depositional overlap is the geographical extension of the limestone over the terrigenous formation, if erosion is taken into account.

To some it would seem almost incredible that the Beekmantown which has such a tremendous apparent thickness near the lake was not deposited over what are now the Taconic region and the Vermont valley. Seely, in fact, could not believe it. The fact remains that the Beekmantown has not been positively recognized away from the lake in what is to be regarded as the mass that has been in some degree transported from the eastward. Is it possible that it could have been deposited? Is it possible, for example, that the marble is the Beekmantown? Allowing again the necessity for recognizing thrusts, is it possible to explain the present relative position of Chazy-Trenton limestones and the terrigenous rocks of the Taconic hills in Orwell and Sudbury and still have the Beekmantown in the marbles at the east? It would seem that in this connection it is necessary to consider the probability of downfaulting of the marble and that some restoration of the rocks along the eastern border of the Vermont valley would have to be made, as has been done above, in order to weigh the question properly. When such restoration is made the probable Ordovician calcareous rocks of the valley are apparently raised to the level of those which lie on the rocks of the Taconic hills and the presumption grows that the marbles are younger.

To some the explanation of the occurrence of the limestones on the quartzite-phyllite formation by deposition might not appeal. It would then be necessary to account for the relation in some other way, say by thrust. Could a thrust plane have cut through a mass of rocks that lay to the eastward of the present Taconic hills in such way as to carry everything that lay above the calcareous rocks that now occur in the Taconic hills on the toe of the thrust and further in such way as to superpose these Chazy-Trenton limestones on Lower Cambrian, at the same time pushing what lay on the Lower Cambrian still farther west, the mass pushed now having disappeared by erosion? It might be possible, since there seems to be no necessary rule to govern the

way in which a thrust plane would cut having once been initiated. Such explanation might leave Beekmantown at depth somewhere at the east. It magnifies more than ever the principle of thrust and the distance of movement. That we must suppose that such thrust, if it occurred, carried Ordovician limestones on Cambrian seems best shown north of the Taconic hills, where the evidence is strongest for the terrigenous rock ("Red Sandrock") being Cambrian. If it carried the limestones on Cambrian there is it probable that it would have elevated them to Ordovician schists only a few miles to the south in the Taconic hills?

The idea of depositional overlap fits the conditions at Snake and Buck mountains if we recognize the possibility of lateral variation of the Lower Cambrian sands and muds.

The proximity of the phyllite in the Whiting-Weybridge belt to the quartzite of Snake and Buck mountains offers no particular difficulty. The hypotheses mentioned have not been knowingly stretched to meet the facts. They take careful account of studied field relations. Any discrepancies may be put down for the most part as due to differences of assignment of age to certain rocks and to other differences of interpretation.

In the descriptions of the various areas given in the preceding pages, application has been made of some of the ideas that have just been developed. In the lake region there is acceptable evidence which has long been recognized of westward thrust. Perhaps some of the details offered in this paper are new, and perhaps some of the explanations are original. It is plain that we must recognize the present juxtaposition of masses that were once more or less separated. When we find the "Utica" exposed from beneath the mass, which we look upon as having moved from the east, at some distance east of the present lake shore, the probability of extensive movement appeals strongly. We are bound to consider the possibility that much of the calcareous rock now exposed in the lake region is transported rock. If such could be established with much certainty, our ideas of sedimentary provinces might require modification in some measure. We do not now view the rock where it was originally deposited.

In Benson and Orwell it may appear that we should recognize the probability that a phyllite of Cambrian age now rests on a slate of Ordovician age by thrust. It may be that we shall have to do the same or something similar at the east, but there the conditions are more obscure.

The possibility of extensive thrust or of any geographically extended thrust between the plateau and the Taconic range does not seem to have received much attention or credence. The evidence for thrust overlap has been cited and the question discussed above. It remains to consider a few localities more specifically than has been done.

Apparently, without doing violence to the hypothesis of Cambrian or post-Cambrian folding and erosion and subsequent Ordovician overlap, or even to the idea that the latter in some way brought terrigenous rocks to rest on the limestone that rests on supposed Cambrian, it is possible to imagine that at some time after the overlap occurred, possibly after a period of erosion, but not necessarily, during a period of compression a part of the Cambrian quartzite-schist formation was broken and thrust through and over the limestone. In this way a schist could have come to overlie a limestone or a marble and might appear in a greatly disturbed region to be conformable. But the possibilities seemingly do not end here. If the Ordovician limestone were succeeded upward by terrigenous rock, in some such way as described above, or otherwise, these might even be overthrust by older terrigenous rocks so that Cambrian quartzite or schist might come to lie on Ordovician schist, while the former underlay the limestone at depth.

It appears that the metamorphism shown by the schist of the Taconic range, which it should be noted in many cases, does not exceed that shown by the rocks of some of its foothills, could readily have been produced in muds of Cambrian age and if these should have by thrust been elevated and shoved westward on Ordovician calcareous rocks, they might readily have come into such relation with less altered or originally somewhat different terrigenous rocks as to give an appearance of being wholly different in age, which aspect would be heightened by the fact of their position relative to the limestone. In a region of thrust lithological transitions as indications of increasing metamorphism in relatively undisturbed rocks and therefore as indications of similar age, may have unsuspected significance.

The relations around Bennington are very complicated and those are apparently most so which at first appear simple. It would appear on the basis of general unity of structure of the rocks over a wide region that the conditions at Bennington should be capable of any explanation which should essentially satisfy the conditions farther north in the Vermont valley. On the basis of downfaulting, evidence for which is as strong at Bennington as at any place in the valley, one may attempt a restoration like that which was imagined for the valley around Dorset. The elements of uncertainty are many. The conditions south of the latitude of North Bennington are somewhat different from those north of it, which lends some support to the idea of transverse or east-west faulting between Mt. Anthony and West Mountain.

The elevation of the surface of the valley quartzite south of Bennington to that of the plateau would carry a certain amount of the calcareous rocks of the Cambrian upward, but it is not clear that it would carry all as the interbedded rocks along the western side of the valley south of Bennington may not rest on

quartzite. The proximity of the sheared and otherwise greatly deformed dove-colored limestone and its associated rock just east of Mt. Anthony, south of Bennington town, to interbedded rocks practically contiguous with them on the east, certainly suggests overlap such as is found and more plainly seen at the north. In the imaginary elevation of the interbedded rocks of the valley along the western portion south of Bennington, apparently beneath them would be carried upward some younger rock which had been overlapped by them. The conditions so far imagined give us apparently old rock resting against younger rock along a reverse fault and a thrust plane. Perhaps on the principle of differential normal faulting in the region, the Mt. Anthony ridge would have to be elevated somewhat in this process of restoration. The crystalline limestones and marbles underlying Mt. Anthony are relatively undeformed internally, presenting in their clearly-bedded condition a contrast to the marbles farther north; they are highly crystalline, but to a large extent not mashed and crushed. Directly east of them the bluish-gray limestone and its gray associate are greatly deformed internally, largely through shearing and brecciation. It would appear that this evidence of compression with the general field relations could be taken to mean that there had been a movement of one rock mass on another and the two masses which seemingly would have been involved are the marbles of Mt. Anthony and the sheared rocks just east of them. The marbles are presumably younger than the other rocks. Walcott found certain fossils (Trenton) which would seem to indicate such a probability; the writer found certain fossils which indicate Chazy age for the sheared rocks (see above). The Chazy has apparently broken and ridden upward on the Trenton along a reverse fault plane now marked by the rather extended zone of strong brecciation south of Bennington.

The marbles of Mt. Anthony are capped by schist or phyllite. Along the ridge southward near Carpenter Hill the rocks along the summit and eastern slope are interbedded black phyllite, sericite schist and quartzite. Along a scarp which extends from Carpenter Hill nearly to Pownal Center these terrigenous rocks, for some of the distance at least, rest against the interbedded series of the Lower Cambrian. South of Pownal Center the surface rocks of the ridge are largely crushed black phyllites, often pyritiferous, or chlorite-sericite schist. The schist mass bends southeasterly and cuts across the strike of the interbedded and other rocks northward, finally abutting against the massive, granular quartzite of the plateau.

West of Carpenter Hill is the crushed limestone of North Pownal with some sheared, bluish or dove-colored rock along the eastern part of the mass. On this limestone and jammed in with it is the black, pyritiferous phyllite, the same rock that surrounds

it. Between Carpenter Hill and the limestone hill at North Pownal are areas in which patches of phyllite and limestone are intermingled at the present surface. In North Pownal the limestone rests on the schist; it does also west of the Hoosic River, north of Pownal station. The field relations all about speak with emphasis of former strong compression of the region.

Reckoning with the idea of an overlap of Ordovician calcareous rocks on an old Cambrian surface, as developed in connection with apparent relations at the north, and with the evidence of severe compression which is everywhere manifest, the present relations seem to be capable of at least partial explanation. It would seem that except for normal faulting their relations must recognize deformation by powerful compression and that the structural characters of the rocks show that deformation took place largely in the "zone of fracture." The evidence is good that many of the rock masses have come to be where they are now as the result of disturbance by rupture and displacement.

The interbedded terrigenous rocks on Carpenter Hill are counterparts of similar rocks on which the Ordovician limestones rest in the northern part of the Taconic hill region. The schist of Mann and Mason hills, except for its more abundant chlorite, is like that of West Mountain. The dove-colored rock and its gray dolomite are like those in Benson and Orwell, except for greater metamorphism; they are much like those in Brandon.

Proceeding with the strong feeling that has come from actual and extensive examination of the whole region it seems that the Bennington area does not differ essentially from other areas of the Taconic hills near the Vermont valley that have been discussed. It appears that under compression the rocks of the region were broken by reverse faults. It would seem that the members of the Lower Cambrian series were displaced with reference to each other and that the members of the overlying Ordovician rocks were also displaced with reference to each other. It seems possible to imagine that the quartzite-schist mass was either ruptured without much folding or that it was folded and overturned and then ruptured. The marbles of Mt. Anthony were protected from pronounced deformation by a great fracture, probably a reverse fault, that cut up through them. At Carpenter Hill and southward the crush zone apparently dies away. The quartzite-schist mass was apparently either folded and overturned or ruptured and pushed up, perhaps both. The calcareous rocks of North Pownal were caught and mashed and the schist jammed in with them and carried over them; it was also apparently carried over Mt. Anthony. On the basis of restoration, the Lower Cambrian calcareous rocks may once have overlapped the rocks that formerly lay on the Mt. Anthony ridge. In testing the validity of the interpretation, one must recall contrasts in the different rocks with reference to metamorphism. The schist and

for the most part the Ordovician calcareous rocks were subjected to conditions different from those within the mass that overrode them. The probability of overlap by lateral thrust is strong, on the basis of what is known farther north, but its extent is wholly uncertain. All thrust relations have been thoroughly disguised by normal faulting. Whether any of the Ordovician calcareous rock has been much displaced by lateral thrust it is not possible to tell.

North of North Bennington we find the counterpart of the dove-colored rock which occurs south of Bennington, and which seems to be Chazy, resting on the phyllite, although greatly deformed. Whether this rock is substantially in place it is not possible to decide. On the basis of a restoration it would be lifted to some extent and might come to the level of similar rock now found on the southern slopes of West Mountain. Erosion, as well as faulting, have operated to obscure relations here.

It is still maintained that by a combination of reverse faulting and lateral thrusting, a portion of the floor on which the Ordovician rocks apparently lie, whether by deposition or otherwise, could be carried over the limestone and perhaps give the appearance of being something very different from what it really is.

Regarding apparent conformability; this might be simulated. Logan has distinctly called attention to the superposition of certain rocks on others which seem to be conformable, but which give the strongest possible impression of being very different in age and speaks of the probable greater age of those which are superior in position.

There is apparently nothing which requires that a thrust plane should cut in any particular way through the rocks that are interposed, so to speak, in its path except a variable resistance. It might have undulated in the most irregular fashion at some places and have been fairly regular at others. At times it might have passed from a horizontal direction to one nearly vertical, and might have cut downward as well as upward. In cases where patches of limestone rest on a schist, which in turn rests on a marble presumably by minor thrust and where all are overlapped by thrust, it is possible to imagine that these patches either represent rock that is where it was before overlap by a thrust which cut above them, or that it has been carried there by the thrust cutting down into limestones farther east and moving some of that rock with the overriding mass. They would belong in a different category in one case from what they would in the other, being simple or displaced erosion outliers in the former case and thrust erosion outliers in the latter. The question of the extent to which thrusts may have moved masses of Ordovician limestone or marble, small or large, it is of course impossible to decide. The possibility apparently needs to be recognized.

North of Brandon the thrust apparently did not raise Cambrian schist and push it on marble, but only the interbedded series was thrust on the marble.

Northward it may be that the thrust along the western edge of the plateau disappears and that there is only one thrust plane. The eastern thrust at the south may be a minor one compared with that which drove the Lower Cambrian rocks and their load over the "Utica," and possibly may have been of widely different date.

It is interesting to note that apparently nowhere west of the plateau and east of the margin of the thrust as now developed by erosion along Lake Champlain or in the Taconic hills has the base or basement of the presumably Lower Cambrian been exposed.

In the early stages of the deformation which was to culminate in lateral overlapping thrusts of the Cambrian rocks, the whole floor of these rocks and their overlying load under the tremendous compression were probably folded and crumpled. There were probably developed many reverse faults of varying throw, some of which were probably very small. At this time the rocks undoubtedly also were strongly sheared. Schistose structure was developed in the impure muds, cleavage in the slates, and folds and ruptures in the quartzites. Similar deformations were produced in the overlying limestones.

The dates of these displacements may only be conjectured. In view of the apparent nature and magnitude of the regional deformation one cannot be sure that some later Paleozoic strata may not have once been present in the region.

At some post-Ordovician period the strata were cut by dikes of igneous rock, which in many places cut through the displaced rocks from the substratum beneath. So far as the writer knows, there is no evidence that sets the date of the intrusion and it may have been post-Carboniferous.

It is not easy to discern how much deformation of the thrust planes by folding occurred subsequent to their formation. East of Brandon the apparent plane of overlap of the interbedded series of the Cambrian does not seem to have been much deformed. Irregularities in thrust planes, which are more probably irregular than regular at the outset, by subsequent compression of the region seemingly would not be easy to see. If the thrusts were of pre-Devonian date it seems as though there would be more evidence than is apparent of subsequent deformation in the Appalachian folding of post-Carboniferous time. The probability of a late date for the big thrusts on this basis grows stronger.

The presence of thrusts in the region on the scale that has been described in part and postulated in part greatly complicates the question of the character and extent of any folding that has

been assumed to have occurred at the close of Ordovician time in this region. The assignment of date to the structural features of the rocks of a region like that of western Vermont depends upon one's viewpoint.

It seems reasonably clear that at some time subsequent to the production of the major features of the region that are due to compression, there came a period of extensive deformation by normal faulting. It would seem that it was at this time that the structural outlines of what are now the Vermont valley and Champlain lowland were formed. Between what is now the western edge of the Green Mountain plateau and the region now represented by the Taconic range, the rocks were dropped, producing a great structural trough. Northward was formed the outlines of the Champlain lowland between the plateau on the east and the Adirondacks on the west. Considering the down-faulted region as a whole the movement was differential and involved flexures as well as actual ruptures. The date at which this deformation occurred again can only be conjectured. Possibly it occurred at the time when similar deformations outlined the great Triassic troughs of our Atlantic border.

It seems not unlikely that during the time of post-Triassic faulting in the eastern part of the country there might have been renewed disturbance of this general region and that some of the fault lines now marked by scarps in the Taconic hills and elsewhere may belong to this period of disturbance. Such displacements are not to be confused, however, with reverse faults. It is, however, often not possible to decide whether certain obvious displacements between interbedded quartzites and phyllites of the Taconic hills are reverse or normal faults.

Some of the displacements along Lake Champlain which have been regarded as reverse faults or thrusts and are marked by scarps are apparently really normal faults within thrusted masses. The margin of the thrust is really at a distance from the scarps in question. For example, the displacements on the west of Snake and Buck mountains and west of the Orwell and Benson hills are probably normal faults cutting through a great lateral thrust. These masses were covered at one time and have been exposed by erosion. They stand higher now than the rocks at the west of them because the latter were dropped and the quartzite was carried downward beneath them. The thrusts extended west of these scarps an indeterminate distance, and apparently often, if not usually, across the lake, at least.

There is apparently nothing definite in the region to tell whether any of the thrusts were the results of previous erosion. It is true that east of Brandon and at other places the interbedded series lies on the marble and it is probable that other Cambrian rocks lie on marble; but it seems conceivable that these conditions could have been produced even though there were a

mass of rocks above the limestones now represented by the marbles by reason of the way the thrust plane could have cut through the mass.

It is not necessary that we should assume that the marbles were not covered by other rocks when these thrusts occurred. Such has not intentionally been the argument; the explanation of the particular kind of terrigenous rock that now covers the marble at places is apparently one problem to be solved. A great shear seemingly might have been as effective as erosion in truncating a folded series. This statement would seem to apply generally and to fit the conditions along the lake as well as those near the plateau.

The present physiography. It has been a widely-accepted theory that during middle and late Mesozoic time a large portion of the Atlantic border of our country was reduced by the forces of subaerial erosion to a great peneplaned region, and that in succeeding Tertiary time the region was elevated by an extensive warping movement. According to this theory the present physiography is to be explained as the result of the renewed action of the base-levelling agencies as the region was gradually elevated. For certain regions it does not appear that any better theory has been advanced to explain the present conditions within them.

Accepting this view, the present physiographic outlines of western Vermont apparently must have been shaped along lines that had been determined by the great deformations which the region had suffered. The rocks in the different parts of western Vermont, whether the region was one of early folding and much later thrusts or one of folds and thrusts independent of pronounced earlier deformation, had been brought into such relative positions that during late Mesozoic time, allowing for some erosion, there was produced much the same relation that we see today from west to east across the State: a great truncation of perhaps lofty masses and exposure of rocks of one age here and another there. We note the oldest rocks at the east and the youngest at the west, as far as exposure has gone. The structural outlines of the Vermont valley and Champlain lowland had presumably already been laid down by the downfaulting of great blocks of soft rocks between masses of more resistant crystallines. Although all were alike presumably reduced to a peneplain in late Cretaceous time, upon later elevation the forces of erosion discovered the downfaulted masses of softer rocks and wore them rapidly away.

The present physiography of the region gives some hints of the deformations which it has undergone, and a gross surface section across the State adds something more; but it must be apparent that the physiography by itself is wholly insufficient to explain the complicated structure of the rocks of western Vermont.

SUPPLEMENTARY NOTE.

Some of the names in this paper designating fossils from exposures studied by the writer are used chiefly as general descriptive terms for forms whose identities the nature of the material would often make it difficult to establish. As indices to the horizons of the containing rocks their values have been recognized in many instances by reason of concomitant features, such as reasonably apparent stratigraphic associations with other rock whose identity could seemingly be more conclusively fixed, and from occurrence in similar rocks at other places in the same region with other and different fossils whose identities were more obvious. Particularly among terms used for such general descriptive purposes the names *Pleurotomaria* and *Murchisonia* were applied to markings which strongly resemble either some of the species of *Pleurotomaria* or some of those of *Murchisonia* as described in the older literature to which the general reader probably would most likely first refer, such as the Paleontology of New York by James Hall, or early publications of the Geological Survey of Canada by Billings, as well as the early descriptions of the formations of Vermont. Most of the forms assigned to *Murchisonia* by earlier writers are now referred to other genera (*Lophospira*, *Hormotoma*, etc.), and the same is true for *Pleurotomaria.*

Other names which have been used in reference to fossils are obviously citations from the literature and in such connection are employed without presuming to pass upon their validity or synonymy.

Certain other names have been employed also because of their use by others with reference to Vermont formations in describing certain characteristic fossils and in making comparison thereby with rocks of other regions. In such cases attempt has not usually been made to establish with absolute positiveness just what names in the latest synonymy of Ordovician fossils should apply to the forms referred to. In the list given beyond certain probabilities are indicated.

The general structure of the region suggests that, so far as preservation of fossils in certain disturbed and somewhat metamorphosed strata permits, it may prove desirable to undertake studies designed to draw comparisons among fossils of different localities and rocks in the general Champlain region in order to obtain further light on the probable extent of the thrust deformations which the region has obviously suffered, and to ascertain if any peculiar or anomalous faunal features exist in the region which could be ascribed to such disturbances as the foregoing paper has discussed.

It may perhaps be said that the older names have an historical value in tracing the progress of knowledge of the rocks of western Vermont; but better knowledge of the exact affinities of the fossils is doubtless required before the ancient geographic relations of those rocks may be fully understood.

Name used.	Possible or probable emendation.
Bellerophon sp.	Probably *Sinuites cancellatus*, Hall.
Ophileta complanata, Vanuxem.	Possibly equivalent to some one of the forms described as *O. compacta*, Salter.
Maclurea magna, Emmons.	*Maclurites magnus*, Lesueur.
Strephochaetus sp.	*Girvanella*, probably *ocellata*, Seely.
Trinucleus concentricus, (*Trinucleus concentrica* of various authors).	*Cryptolithus tesselatus*, Green.
Graptolithus pristis.	*Graptolithus pristis*, Hall. (Possibly *Diplograptus* sp. or *Glossograptus* sp.)
Prasopora sp.	*P. simulatrix*, var. *orientalis*, Ulrich. (Some specimens collected by the writer at South Hero were examined by Dr. Ruedemann of Albany in connection with studies of Trenton fossils from Grand Isle and identified as *P. simulatrix*, var. *orientalis*, Ulr.[1] In view of the recognition of this form in the Champlain valley the writer prepared radial and tangential sections of specimens collected by him at the grist mill, one mile west of Orwell village, and on the lake shore in Orwell just north of the Benson line, and compared with the descriptions and figures given by Ulrich in the Geology of Minnesota, vol. 3, part 1, 1895, pp. 245-248, plate 16, and found his specimens also to be *P. simulatrix*, var. *orientalis*, Ulr.)

[1] Personal communication.

BIBLIOGRAPHY.

1845—ADAMS, C. B. First, Second, Third and Fourth Annual Reports on the Geology of Vermont.

1846—EMMONS, E. Agriculture of New York.

1861—HITCHCOCK, E., and Others. Geology of Vermont, 2 vols.

1861—BARRANDE, J., LOGAN, SIR W., HALL, JAMES. Correspondence on the Taconic System and the age of the Fossils found in the Rocks of Northern New England and the Quebec Group of Rocks. Amer. Jour. Sci. Vol. 31.

1861—BARRANDE, J. Documens Anciens et Nouveaux sur la Primordiale et le Systéme Taconique en Amerique. Bull. Soc. Géol. de France. Vol. 2.

1863—LOGAN, SIR W. E. Geology of Canada, Text and Atlas.

1877—DANA, J. D. An Account of the Discoveries in Vermont Geology of the Rev. Augustus Wing. Amer. Jour. Sci. Vols. 13 and 14.

1877—DANA, J. D. On the Relations of the Geology of Vermont to that of Berkshire. Amer. Jour. Sci. Vol. 14.

1879—DANA, J. D. On the Hudson River Age of the Taconic Schists. Amer. Jour. Sci. Vol. 17.

1880—DANA, J. D. Note on the Age of the Green Mountains. Amer. Jour. Sci. Vol. 19.

1882—DANA, J. D. The Geological Age of the Taconic System. Quart. Jour. of the Geol. Soc. Aug., 1882.

1884—GEIKIE, A., PEACH, B. N., and HORNE, J. The Crystalline Rocks of the Scottish Highlands. Nature. Vol. 31.

1884—DANA, J. D. On the Southward Ending of a Great Synclinal in the Taconic Range. Amer. Jour. Sci. Vol. 28.

1885—FORD, S. W. Great Fault, Schodack Landing, N. Y. Amer. Jour. Sci. Vol. 29.

1885—DANA, J. D. On Taconic Rocks and Stratigraphy, with a Geological Map of the Taconic Region. Amer. Jour. Sci. Vol. 29. See also Vol. 33, 1887.

1886—MCCONNELL, R. G. Report on the Geological Features of a Portion of the Rocky Mountains. Ann. Rept. Geol. Surv. Can. Vol. 2.

1886—DANA, J. D. Berkshire Geology. A paper read before the Berkshire Historical and Scientific Society, Pittsfield, Mass., Feb. 5, 1885.

1886—BRAINERD, E. and SEELY, H. M. Notice of Geological Investigations along the Eastern Shore of Lake Champlain. Bull. Amer. Mus. Nat. Hist. Vol. 1.

1888—PEACH, B. N., HORNE, J., GUNN, W., CLOUGH, C. T., HINXMAN, L., CADELL, H. M. Communicated by GEIKIE, A. Report on the Recent Work of the Geological Survey in the North-West Highlands of Scotland. Quart. Jour. of the Geol. Soc. Vol. 44.

1888—WALCOTT, C. D. The Taconic System of Emmons and the Use of the Name Taconic in Geologic Nomenclature. Amer. Jour. Sci. Vol. 35.

1888—DANA, J. D. A Brief History of Taconic Ideas. Amer. Jour. Sci. Vol. 36.

1888—MARGERIE et HEIM. Dislocations de l'écorce terrestre. Zurich, 1888.

1888—ELLS, R. W. Second Report on the Geology of a portion of the Province of Quebec. Ann. Rept. Geol. and Nat. Hist. Survey of Canada. Vol. 3, Part 2.

1890—WALCOTT, C. D. The Fauna of the Lower Cambrian or Olenellus Zone. Tenth Annual Report of the Director, U. S. G. S.

1890—BRAINERD, E. and SEELY, H. M. The Calciferous Formation in the Champlain Valley. Bull. Amer. Mus. Nat. Hist. Vol. 3.

1891—Hayes, C. W. The Overthrust Faults of the Southern Appalachians. Bull. Geol. Soc. Amer. Vol. 2.
1891—Brainerd, E. The Chazy Formation in the Champlain Valley. Bull. Geol. Soc. Amer. Vol. 2.
1891—Wolff, J. E. On the Lower Cambrian Age of the Stockbridge Limestone. Bull. Geol. Soc. Amer. Vol. 2.
1891—Walcott, C. D. Correlation Papers, Cambrian. Bull. U. S. G. S. No. 81.
1892—Willis, Bailey. The Mechanics of Appalachian Structure. Thirteenth Annual Rept. of the Director, U. S. G. S. Part 2.
1892—Van Hise, C. R. Correlation Papers, Pre-Cambrian. Bull. U. S. G. S. No. 86.
1893—Darton, N. H. On two Overthrusts in Eastern New York. Bull. Geol. Soc. Amer. Vol. 4.
1893—Willis, B. and Hayes, C. W. Conditions of Appalachian Faulting. Amer. Jour. Sci. Vol. 46.
1893—Foerste, A. F. New Fossil Localities in the Early Paleozoic. Amer. Jour. Sci. Vol. 46.
1893—Dale, T. Nelson. On the Structure of the Ridge between the Taconic and Green Mountain Ranges in Vermont. Fourteenth Ann. Rept. of the Director, U. S. G. S. Part 2.
1894—Pumpelly, R., Wolff, J. E., and Dale, T. N. Geology of the Green Mountains in Massachusetts. Monograph U. S. G. S. No. 23.
1894—Whittle, C. S. Algonkian Rocks in Vermont. Jour. Geol. Vol. 3.
1895—Dale, T. N. Structural Details in the Green Mountain Region and in Eastern New York. Sixteenth Ann. Rept. of the Director U. S. G. S. Vol. 4, Part 1.
1895—Van Hise, C. R. Principles of North American Pre-Cambrian Geology. Sixteenth Ann. Rept. of the Director U. S. G. S. Vol. 4, Part 1.
1896—Brainerd, E. and Seely, H. M. The Chazy of Lake Champlain. Bull. Amer. Mus. Nat. Hist. Vol. 8.
1898—Dale, T. Nelson. The Slate Belt of Eastern New York and Western Vermont. Nineteenth Ann. Rept. of the Director U. S. G. S. Part 3.
1899—Emerson, B. K. The Geology of Eastern Berkshire County, Mass. Bull. U. S. G. S. No. 159.
1899—White, Theodore G. Upper Ordovician Faunas in Lake Champlain Valley. Bull. Geol. Soc. Amer. Vol. 10.
1901—Ruedemann, R. Hudson River Beds near Albany and their Taxonomic Equivalents. N. Y. State Mus. Bull. No. 42.
1902—Willis, Bailey. Stratigraphy and Structure, Lewis and Livingston Ranges, Montana. Bull. Geol. Soc. Amer. Vol. 13.
1902—Perkins, George H. The Geology of Grand Isle. Third Report of the State Geologist.
1904—Dale, T. Nelson. The Geology of the North End of the Taconic Range. Amer. Jour. Sci. Vol. 17.
1905—Raymond, P. E. The Fauna of the Chazy Limestone. Amer. Jour. Sci. Vol. 19.
1906—Merrill, G. P. Contributions to the History of American Geology. U. S. Nat. Mus. Report for 1904, No. 135.
1906—Edson, G. E. Geology of St. Albans and Vicinity. Fifth Report of the State Geologist.
1906—Seely, H. M. Beekmantown and Chazy Formations in the Champlain Valley. Fifth Report of the State Geologist.
1907—Keith, Arthur. Roan Mountain Folio. Geological Atlas of the U. S. No. 151.

1908—Perkins, George H. Preliminary Report on the Geology of Chittenden County. Sixth Report of the State Geologist.
1908—Edson, G. E. Geology of the Town of Swanton. Sixth Report of the State Geologist.
1908—Perkins, George H. Preliminary Report on the Geology of Franklin County, Vt. Sixth Report of the State Geologist.
1909—Ruedemann, R. Types of Inliers Observed in New York. Bull. N. Y. State Mus. No. 133.
1909—Van Hise, C. R. and Leith, C. K. Pre-Cambrian Geology of North America. Bull. U. S. G. S. No. 360.
1909—Schuchert, C. Paleogeography of North America. Bull. Geol. Soc. Amer. Vol. 20.
1910—Dale, T. N. The Cambrian Conglomerate of Ripton in Vermont. Amer. Jour. Sci. Vol. 30.
1910—Seely, H. M. Preliminary Report on the Geology of Addison County. Seventh Report of the State Geologist.
1910—Perkins, George H. Geology of the Burlington Quadrangle. Seventh Report of the State Geologist.
1910—Kemp, J. F. and Ruedemann, R. Geology of the Elizabethtown and Port Henry Quadrangles. Bull. N. Y. State Mus. No. 138.
1911—Ulrich, E. O. Revision of the Paleozoic Systems. Bull. Geol. Soc. Amer. Vol. 22.
1911—Gordon, C. E. The Geology of the Poughkeepsie Quadrangle. N. Y. State Mus. Bull. No. 148.
1912—Willis, Bailey. Report on an Investigation of the Geological Structure of the Alps. Smithsonian Miscellaneous Collections. Vol. 56.
1912—Richards, R. W. and Mansfield, G. R. The Bannock Overthrust. Jour. Geol. Vol. 20.
1912—Dale, T. Nelson. The Ordovician Outlier at Hyde Manor in Sudbury. Amer. Jour. Sci. Vol. 33.
1912—Dale, T. N. The Commercial Marbles of Vermont. Bull. U. S. G. S. No. 521. See also Ninth Report of the State Geologist, 1914.
1913—Keith, A. Further Discoveries in the Taconic Mountains. Abstract. Bull. Geol. Soc. Amer. Vol. 24.
1913—Dale, T. N. The Ordovician Outlier at Hyde Manor in Sudbury. Second paper. Amer. Jour. Sci. Vol. 36.
1914—Gordon, C. E. Notes on the Geology in the Vicinity of Bennington. Ninth Report of the State Geologist.
1916—Perkins, George H. The Geology of Western Vermont. Tenth Report of the State Geologist.
1917—Emerson, B. K. Geology of Massachusetts and Rhode Island. Bull. U. S. G. S. No. 597.

THE GEOLOGY OF LAKE WILLOUGHBY.

Elbridge C. Jacobs,
University of Vermont.

Lake Willoughby lies in the western part of the town of Westmore, near the eastern boundary of Orleans County, and some twenty-three miles north of St. Johnsbury. It is one of the most beautiful sheets of water in the United States and would not suffer by comparison with the Alpine lakes of Switzerland. To quote from Mr. Walter Crockett's "Lakes of Eastern Vermont," we have here "a rare combination of lake and mountain scenery, a lake (five miles long and from one-half to one and one-fifth miles wide) of exquisite loveliness set amid bold and rugged mountains, the dark tints of the evergreen forests and the delicate silvery whiteness of the birches being reflected as in a mirror in Willoughby's deep waters. * * * * *" "On either side, at the southern extremity of the lake, like giant guardians, stand Mount Pisgah and Mount Hor, with their Scriptural names, keeping watch over this vision of scenic loveliness." The slopes of these mountains are densely wooded save where erosion reveals nearly vertical cliffs of dark, bronze-colored rocks, slashed with bands and patches of a lighter material. Below the cliffs are enormous talus heaps of granite and other material. Rock falls are frequent, a fall in July of this year blocking the road for several days.

The lake may be likened to the section of a giant calabash gourd, with its broad end lying in the relatively open country and its curving neck penetrating and forming a gap in the mountain range at its southern extremity. The lake shores were formerly impassible to vehicles, communication between the eastern and western valleys being either by boat or else by a mountain road running east of Mount Pisgah. But some sixty years ago a road was built along the eastern (Mount Pisgah) shore and now forms part of the main highway between St. Johnsbury and Newport. Numerous summer cottages and the Westmore Hotel are located along this road towards the northern end of the lake. "Westmore," a girls' camp, was built in 1919 on a commanding hill on the northwestern shore. The camp is closed this season owing to financial difficulties, but will probably be reopened. This

Studies in the Liturgy

of

[illegible]

Second Part

STUDIES IN THE GEOLOGY OF WESTERN VERMONT

Second Paper.

CLARENCE E. GORDON,

MASSACHUSETTS AGRICULTURAL COLLEGE

TABLE OF CONTENTS.

INTRODUCTION.

A description of the principal physiographic divisions of western Vermont and a general statement of the characters distribution and certain other features of the various rock formations found in those divisions may be found in the first paper under this title, published in the Twelfth Report of the State Geologist. These were intended to serve for guidance in following the description and discussion, offered in the same paper, of a number of observations made in certain parts of western Vermont which dealt chiefly with the deformations of the different rocks. For the present paper, which gives an account of studies of the field relations of the rocks in other parts of western Vermont, the general statement made in the preceding report is considered sufficient and need not be repeated nor amplified in this one.

The physiographic divisions mentioned are the prominent ones of the present surface of this part of the state. Each, of course, shows many minor topographic variations incident to the character and structure of the underlying rock and the modifying effects of erosion and other agencies, such as glaciation. Except for a quarry here and there the average observer is probably impressed only by the grander features of the surface; it is their charm that invites the tourist to motor through this part of Vermont or impels the summer resident to build his camp on some hill or mountain side.

So conspicuous indeed are these larger divisions of the landscape they may easily impress the geological student as possessing a significance beyond that which they really have. Geological accounts of different parts of the region often accentuate these more or less modern features and it seems as though in a provincial treatment of them their true geological history and connections have been more or less obscured. The more ancient secondary structural features of the rocks bear no necessary relation to the present physiography of the region, which is due in part to later deformations or disturbances and in part to repeated erosion.

Over the present surface of western Vermont there is shown a confusion in the arrangement of the rocks that is very baffling. This confusion is very clearly due in large measure to the various deformational and metamorphic changes which the rocks have suffered and to certain primary features, such as lateral variations in certain members. Added to these are the effects of erosion and glaciation. Over large areas correlation may not be made by direct aid of fossils, and one must rely upon other criteria of various sorts. Particular mention should be made of the extensive mantle of surface material, either bowlder drift, sand or

clay, which conceals large areas and imposes great difficulties in working out the structural details of most localities.

The student who confines his studies to a small portion of the region may gain a glimpse of the nature of the structure of the rocks in some cases; in others he may be quite confused. It is necessary to carry one's studies over a wide area to see into the plan that apparently prevails over the region as a whole.

The studies described in this paper and the earlier one were undertaken in the hope that it would eventually prove possible to examine in a somewhat critical way a large number of outcrops in all four of the different divisions of the region, which the writer has defined, with the purpose of getting light on the general plan of structure of the rocks and in order to discover if any marked degree of unity prevails throughout. For reasons that will generally be understood it has been necessary to publish accounts of the work at various stages of its progress. At this writing there still remains the larger portion of the mass of rocks contained within what is known as the Taconic range, which is a territory which the writer had reserved in his mind for future study. From studies already made in parts of the range it seems likely that in its main features it may finally be reduced to a plan of structure like that of other divisions which now bear little physiographic resemblance to it. Finally, it seemed probable that a more careful inspection than has yet been possible could be given to the western ranges and other masses of the Green Mountain plateau to see to what extent the rocks now lying west of the plateau could be traced into it and whether the deformations present in it are similar in plan to those found among the rocks now lying west of it. Experience has served to show that apparently only by a broad survey of the region as a whole is it likely that one may grasp the true significance of the relations within and among its different parts.

The general similarity shown by the field relations in widely separated areas indicates a fundamental unity of structure in all of them. Moreover, excursions into areas contiguous to Vermont, such as western Massachusetts and southern Quebec, as well as published descriptions for other adjoining territory and for districts still more remote suggest that a common plan of structure may prevail over a much wider region than western Vermont.

The work and writings of Professor J. D. Dana,[1] in which he aimed to show the relations (general similarity or unity of plan) between the geological features of western Vermont and those of Berkshire County, Massachusetts, and other areas as well, are well known. The writer's conception of the similarity that exists in the areas described by Dana follows him in maintaining that

[1] On the relations of the Geology of Vermont and that of Berkshire, A. J. S., Vol. XIV, July, 1877.

the "western half of the whole Green Mountain region is eminently a natural area," and that in many primary features, such as general age and general original interrelations, the rocks throughout are similar. The purpose of this paper is to indicate, if possible, the *kind of structure* in which western Vermont possesses unity and to show the apparent nature of the chief deformations which have disturbed the rocks. Numerous descriptions of field relations, in addition to those given in the first paper, will be offered to show the dominant influence of thrust displacements of various magnitudes and of kindred phenomena due to pressure acting upon highly elastic and resistant rock formations associated with weaker and less "competent" strata.

Extent and certain other features of the region described in this paper. A rough estimate of the dimensions of the irregular territory which has been surveyed gives about 900 or 950 square miles. It includes either the whole or large portions of the following-named topographic sheets of the U. S. G. S.:—Rouses Point, St. Albans, Plattsburg, Milton, Willsboro, Burlington, Port Henry, Middlebury, Ticonderoga and Brandon. In a north to south direction it extends from the Canada line approximately to the southern boundary of Leicester in Addison County, and west to east from the New York State boundary to the western margin of the Green Mountain plateau.

The ground gone over has not, of course, all been studied in minute detail; but much of it has been examined with more thoroughness than will appear in the descriptions, in the search made for clues of different sorts, especially for fossils in the more altered rocks found in the eastern portions of the region.

Some parts of the territory have been described more or less fully in the first paper; but in most cases these areas have been reexamined.

The lake region proper, which is included within the physiographic division called the Champlain lowland, seems to call for some sort of specific definition, as it will be frequently mentioned in the following pages. In addition to the lake with its islands there are along its border many areas of various dimensions, often small but again of considerable size, which are underlain by rocks similar to those which form the islands and the lake bottom. Many of these areas are now covered with Champlain clays, or sands brought in by streams entering the lake. In many places outcrops are few, especially where the underlying rock is clearly or apparently the soft shale formation, but at many places limestone beds like those found on the islands project above the surface deposits, forming knolls and ridges. It seems likely that if the clay which is so plentiful over portions of the mainland near the lake were removed these areas would be more or less inundated by the lake waters, even at their lower levels, and that

there would be produced a very different shore line, more numerous islands and a larger water body. A similar operation on the islands would in some cases partition them into smaller units.

Some of the streams which enter Lake Champlain, such as Lewis, Little Otter and Otter Creeks, are for greater or less distances from their mouths hardly more than inundations by the lake waters of narrow channels in the clays, with hardly head enough at the present time to give them perceptible currents; and Dead Creek, a tributary of the Otter, is practically all its way a sluggish stream of this sort. In the case of the Otter the inundation extends from its mouth to the city of Vergennes, where the stream tumbles over a scarp in massive dolomite to the graptolite shales below. For a large part of its course below Vergennes the river flows through a sand plain of its own making and at its mouth it has formed delta levees by which it has tied Fort Cassin to the mainland.

Hog Island, so-called, in the township of Swanton, is a land-tied island, accomplished in this case by the delta deposits of the Missisquoi River.

It thus appears that some islands have become secondarily attached to the mainland and that large areas of the mainland differ from the lake only in the fact that clay takes the place of water. Such considerations may prove helpful to the reader when in the succeeding pages different areas are described and compared with one another.

The studies which were described in previous papers were scattered rather generally over the western half of the state and were conducted in much more detailed and systematic manner in some places than in others. This resulted from the way in which the general problem was from time to time approached.

The rocks first examined were those in the difficult region around Bennington, in the southwestern portion of the state. Six years later (1918) a trip was made through the Vermont valley and parts of the Champlain lowland, Taconic range, and Green Mountain plateau with the definite purpose of searching for a general plan of structure among the rocks over a wide region which might serve as a key to the relations around Bennington. Much that was planned for this trip had to be abandoned on account of illness. In the seasons of 1919 and 1920 a somewhat systematic study was made of a wide surface section from the Green Mountains to Lake Champlain, in the towns of Brandon, Sudbury and Orwell.

From these several studies, especially from those made in Brandon, Sudbury and Orwell, various inferences were drawn, some of which were given a broad application in the interpretation of the structure of the region. The views expressed were based on personal work. Some found support in the writings of other

workers while others were apparently new and clearly called for such substantiation as further study might give.

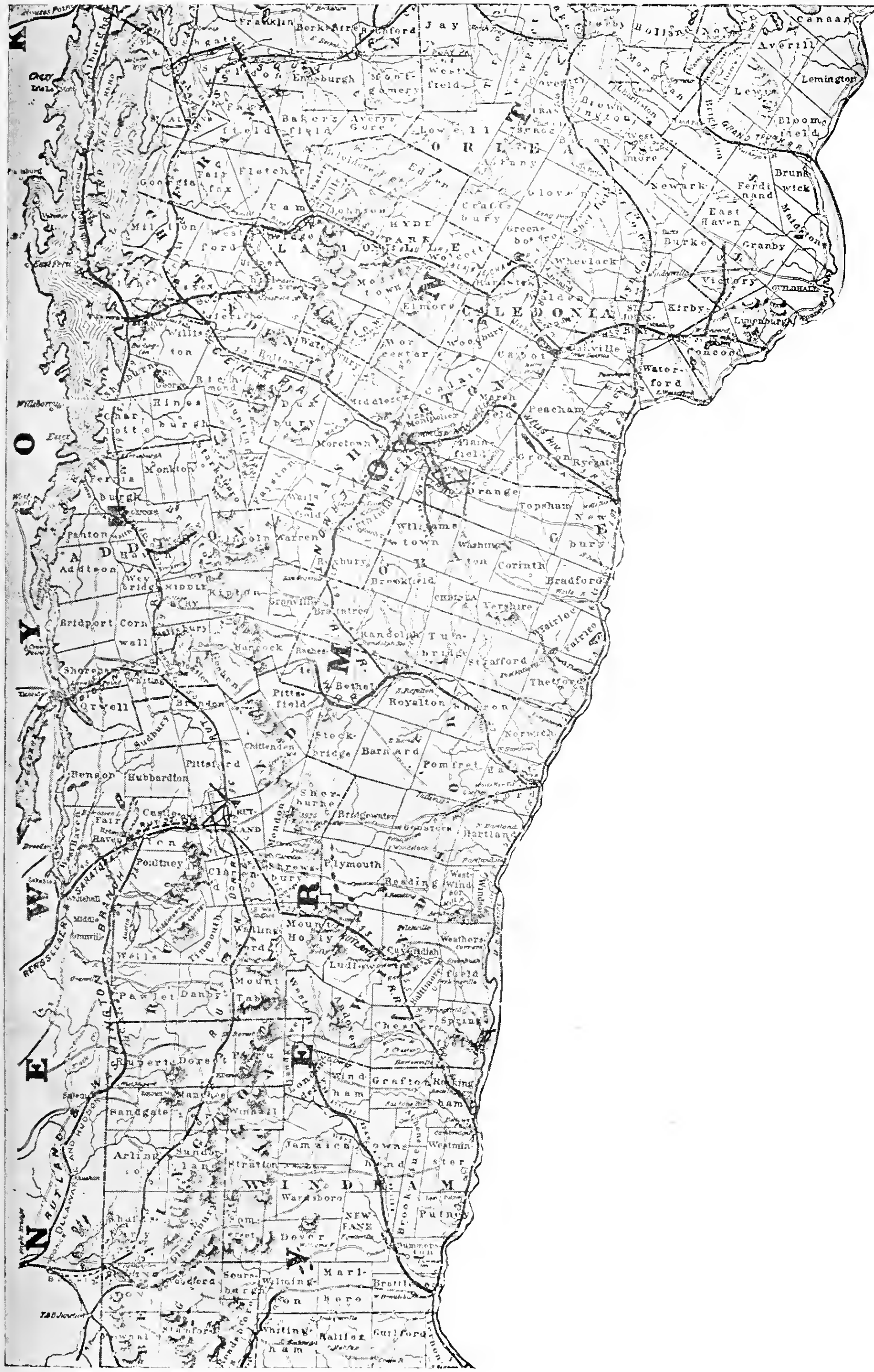
The brief studies which it had been possible to make in various parts of the Champlain lowland, up to the season of 1921, had tended to strengthen the belief that the whole of western Vermont is "eminently a natural area" and had suggested that the lowland would probably afford the field relations that would serve best in testing certain views regarding structure.

The Champlain lowland makes up a large portion of western Vermont. It merges quite imperceptibly with the Vermont valley, both physiographically and geologically, and except as disguised by certain primary differences of the rocks and by faulting may reasonably be shown to merge with the Taconic range, whose foothills as well as the main range itself still show vestiges of the features that are now best preserved over the lowland. The lowland then seems to be only a physiographic subdivision of a large region whose genetic features are essentially identical throughout. Even in its relation to the Green Mountain plateau the designation of lowland should not be understood to convey the idea of strong contrast between the two, for over long distances there is a most gradual transition topographically and almost complete identity or unity geologically between adjacent portions of them.

Notwithstanding these recognizable transitions between the lowland and the higher lands of the Taconic range and the Green Mountain plateau and the presence of high hills at many places in the lowland this division is structurally a sunken region with respect to surrounding higher surfaces. The Vermont valley may be viewed as the southward extension of the lowland between the plateau and the Taconic range. Since in its breadth from west to east the lowland therefore comprises counterparts of the marginal portion of the plateau, of the Vermont valley and of the Taconic range one finds within it relations that are often preserved only in much more fragmentary conditions in the other divisions, for one reason or other.

The meaning of the comparisons which have just been made of parts of the region with each other really comes out only after careful field study; but it is hoped that the discussions which will follow, taken with those which were given in the first paper, will enable the reader to see the force of the contention that different parts of western Vermont possess strong similarities in a number of ways.

A survey of the lowland was carried on during the seasons of 1921 and 1922, together with some study of the marginal portions of the plateau. The territory covers many square miles. It was necessary to confine attention to those field relations that bear particularly upon structure, simply in order to get over the ground and not leave untouched any large number of places that



Township map of Vermont.

might throw light on the main problem. Naturally during the work many other fascinating problems appeared which it was necessary to pass by.

DESCRIPTIONS AND DISCUSSIONS OF OBSERVATIONS MADE BY THE WRITER WITHIN THE CHAMPLAIN LOWLAND AND ADJACENT PORTIONS OF THE GREEN MOUNTAIN PLATEAU.

General plan of discussion. As the field studies described herein were the continuation of those discussed in the first paper it has seemed best to make no marked change in mode of treatment. General reference will be given by counties and townships which are shown on the accompanying township map of Vermont. Citations of localities are based chiefly on the topographic quadrangle sheets of the United States Geological Survey.

It may prove useful in some cases to cite observations or interpretations of others in order to develop the writer's viewpoint in respect of relations and structure, and in this paper this will be done along with the discussions of different areas rather than in the form of a general preliminary review, such as was given in the first report.

Because there is often a close relation between topography and geology the topographic features that are of interest in regard to structure will be mentioned at appropriate places.

GRAND ISLE COUNTY.

Townships of South Hero and Grand Isle.

(Plattsburg and Rouses Point topographic sheets.)

General remarks. From observations made in the season of 1920 on the island which includes the townships of South Hero and Grand Isle, suggestions were offered as to how the relations among the formations there present might possibly be explained. These suggestions were made not only on the basis of conditions on the island, but also in the light of careful studies of the field relations at other places in the lake region, particularly in Shoreham and Orwell.

While camping on the island in the summer of 1921, parts of it which had not been personally visited before were inspected and excursions were made to the New York side of the lake.

Principal geological features of the island. The geology of the island has been described in detail by Professor Perkins.[1]

[1] Third Report of the State Geologist, 1901-02, pp. 102-173.

The formations of the island may be briefly described as follows:

1. Limestones, mostly gray or gray-weathering, generally in rather thick beds, frequently very massive, more or less altered by granulation and, perhaps, somewhat in certain cases by dynamic agencies; but generally not marked by clearly visible internal deformation due to shearing. These rocks include a small portion of Brainerd and Seely's "Beekmantown," which is more fully developed on Providence Island just to the south of Grand Isle and parts at least of the same authors' divisions A, B, and C of the Chazy. These rocks occur in somewhat disconnected masses, chiefly in the central and southwestern portions of the island. The Chazy shows much variation in color and the different divisions are recognizable on the basis of fossils. The small area of Beekmantown at the south end of the island was considered by Seely and Perkins to belong to division E of Brainerd and Seely's classification.

2. Other limestones, generally in contrast with those of 1 in being composed of prevailingly much thinner beds, but including somewhat massive blackish rocks of Black River age. All belong to a series which is apparently marked at the base by heavy Black River beds and overlying fairly pure limestones of Trenton age and which ascends through a sequence of mud rocks, all more or less limy, but including fairly pure limestone beds. The members vary in color from gray to bluish-black, the latter usually weathering to a gray. In these rocks granulation is not at all marked. The sequence from base to top is interrupted by displacements so that it is not as well shown on this island as at some other places in the lake region which will be mentioned beyond. The alternations from one kind of rock to another, from fairly pure limestone to more argillaceous material, suggest oscillations of level and other conditions which operated to cause changes in the character of the deposits from time to time and changes in the character of the fauna as well. As would be supposed, there are also shown lateral gradations or variations in the same beds. Frequently limestone apparently takes the form of small lenses in more argillaceous rocks. All the conditions indicate that during the times of deposition of this series, muds were contending with limestones, over which they finally gained ascendency. Some portions of this mud-limestone series are barren of fossils. In others they are scarce. There is an interesting recurrence in low horizons within the shales of forms marking the basal beds which have a typical Trenton fauna ("Glens Falls".)

This formation of limestones and irregularly repeated muddy limestones and limy muds passes upward into the rocks described under 3.

3. Prevailingly blackish, shaly mud rocks, still often if not

usually limy, effervescing with cold dilute acid, but characterized by persistently finer grain. In their bedded features they are not, however, uniformly thinly-bedded shales. The beds can be seen to vary in thickness from a fraction of an inch to an inch or more and are interbedded with siliceous bands of tougher texture which break with subconchoidal fracture and are often from six to eight or more inches thick. These various shaly rocks have over wide areas a splintery character due to pronounced shearing across the bedding, giving a kind of slaty structure.

Contacts of the members given under 1 with those of 2 and 3 are mostly wanting and their structural relations are, therefore, more or less problematical and open to such interpretation as the general structural features of the region might suggest. The higher members of 2 probably pass upward into the lower beds of 3, but there are present well-defined displacements which actual contacts do not seem necessary to demonstrate.

Attention has been directed by different observers to the differences shown at the present time among the formations of the island with regard to the extent to which or the manner in which they have been respectively affected by dynamic agencies.

The rocks belonging to group 3, as defined above, perhaps make up the larger part of the island. They are generally characterized by pronounced deformation. Folding and tilting are common; but even in places where neither of these is marked, they are when only slightly buckled or lying nearly flat distinguished by a strongly developed cleavage. But this shearing structure is not confined to the members of group 3 alone; it is found in much of fine grained limestone of category 2.

This shearing structure has undoubtedly led to confusion in the field among different horizons of the younger members of the Ordovician series. In surface outcrops, particularly small ones projecting through the clay or drift, all that may be visible is an irregular erosion surface of apparently more or less flattish beds which have been sheared into slates which do not differ much in appearance, whether they belong to group 2 or group 3. This circumstance is of importance because without appreciation of it the real character of a rock in its present surface exposure may not be recognized.

From the conditions shown on Grand Isle, Perkins[1] was early led to regard a considerable portion of the limestones with interbedded muds as forming a transitional series between the Trenton and the "Utica." The probable occurrence of such a "transitional series" in the Champlain basin has also been suggested by other observers.[2] From a study of fossils from the younger limestones and shales of the Champlain region, Ruedemann[3] came to

[1] Perkins, Third Report, 1902, The Geology of Grand Isle.
[2] White, Bull. Geol. Soc. Amer., No. 10, 1899, pp. 452-462.
[3] Ruedemann, Twelfth Report Vt. State Geol., 1920, pp. 90-100.

the conclusion that the "Ordovician series ends in Vermont with beds no younger than the Trenton group." The thinly-bedded limestones of the basal beds are true Trenton ("Glens Falls horizon"). The black mud rocks of the Champlain basin in the south (for example, around Panton) consist entirely of Canajoharie shale; in the north they are "prevailingly of the 'Stony Point' shale. In the middle they meet, the 'Stony Point' shale resting upon the Canajoharie shales on Grand Isle and in the Vermont portion of the northern part of the basin."

Most of the rather barren black shale in the northern part of the basin, carrying *Triarthrus becki* and *Glossograptus quadrimucronatus* as its prominent fossils, which extends from the Canadian line southward over the islands of the lake and along the mainland of Vermont, is thought by Ruedemann to be the equivalent of his "Stony Point" shale and to be homotaxial with late Trenton and, therefore, older than true Utica. Ulrich concurs with Ruedemann in the opinion that no true Utica exists in the Champlain basin.

On Grand Isle the thinly-bedded basal Trenton rocks form a ridge about a mile east of the west shore of the island, running from a point southeast of Sawyer's Bay, where they are in proximity to Chazy beds, northward to the latitude of Gordon Landing. At numerous places they yield characteristic basal Trenton fossils. For the most part these beds are not crushed nor sheared, although at some places they have buckled and sheared somewhat, showing clearly that they have experienced lateral pressure. Except where buckled into small folds these rocks appear to lie in a flattish position, dipping gently easterly. They do not appear to form a part of a true anticlinal fold. The western outcrop of the beds forms a slope of variable inclination as now eroded. This slope east of Sawyer's Bay clearly marks a former shore of the Champlain water body. There is a topographic breach in this Trenton ridge northeast of Rockwell Bay. It seems probable that these rocks formerly had an extension west of their present western margin.

The muddy limestones with included shaly layers which occur along shore north of Rockwell Bay appear to be younger than the beds forming the ridge just described. They also lie in flattish position, but take on a slight northerly pitch about one-fourth of a mile north of Rockwell Bay. These rocks have strong resemblance to beds which lie above the basal Trenton near Crane Point in Addison County, which will be described more fully later. Around Gordon Landing the rocks are of more muddy texture than are those southward and are even more thickly-bedded. Near Gordon Landing, although bedding is distinct, the rocks are sheared with easterly dipping cleavage, so that surface exposures away from shore have the appearance of slates.

A little way north of Rockwell Bay, in a layer near the water, *Isotelus* occurs with *Prasopora,* paralleling the conditions near Crane Point where *Prasopora,* which sometimes makes up almost an entire bed in the basal series, as it does also on Grand Isle, recurs occasionally in certain layers of the muddy rocks which lie above the basal series.

Between the west shore of the island at Gordon Landing and the slope of the ridge of basal beds east of it there is much surface covering; but from the general field relations and the attitude of the layers along shore and in the ridge there is nothing that suggests an anticlinal fold so that the so-called younger beds along shore could be interpreted as lying above the basal beds on the western limb of such fold.

North of Gordon Landing the rocks in some places have resemblance to the basal Trenton and at others to the beds north of Rockwell Bay. At the Grand Isle landing of the Cumberland Head ferry in a thick layer near the water-level there were found specimens of *Sinuites cancellatus,* fragments of *Calymene,* and small orthocerata. The thick layer just referred to is succeeded northward and upward by an imperfectly alternating series of layers, some of which are dark colored and sheared, while others are lighter colored, as weathered and usually non-sheared. It is somewhat surprising to observe these rather strongly sheared layers lying between others which show no marked cleavage. Among the mud rocks this condition not infrequently occurs within a considerable thickness of beds which do not show any prominent mass deformation and which often lie nearly flat.

Although the beds near the ferry landing are not greatly deformed, in general there is more evidence of disturbance from pressure in the rocks between Gordon Landing and Camp Vermont than in the shore section south of the landing. This disturbance is shown in the form of minor buckling and occasional ruptures, as well as by mashing and by the shearing which has been mentioned.

There is acceptable suggestion of an east-west fault at Rockwell Bay, the "transition beds" lying against the Chazy, although the contact is not visible. There is also suggestion of a break at Gordon Landing, with the beds at the north occupying the upthrow side.

The ridge that has been described above as composed of the basal Trenton beds can be followed only a short distance north of the latitude of Gordon Landing. Northward over areas that have been mapped as "Utica" the surface outcrops are few and usually not clear as to horizon. In some places the rock might without much hesitation be correlated with the "transitional series" of limestones and shales rather than with the higher black shale beds; but extensive shearing and absence of fossils

make it difficult to decide the matter, particularly in low surface outcrops, such as these rocks usually present.

From Wilcox Cove northward the shore section displays a series of beds which are predominantly shaly, with some bands of siliceous rock, the whole lying nearly flat. While there is some crushing these rocks are not much tilted.

The formation of black shale on this island, and in most of its exposures among the islands to the north, as well as on the mainland, has primary structures which serve to distinguish it from the more limy rocks that are thought to be transitional from the basal Trenton beds into it. Even when strongly sheared the black shale formation may be seen to comprise members of variable thickness, as has been mentioned above, some of which are distinctly shaly, while others are of firmer character and more siliceous. These different members are separated by distinct parting planes which come out most sharply when the rocks have been folded or tilted. But the more shaly or muddy beds are marked in addition by fine laminations which often give an appearance of fine-grained wood. These laminations show most clearly when the rock has been weathered, the weathering process having the effect of emphasizing the slight differences in the composition of the laminae. One is tempted to speculate on the conditions that could have produced these laminations which have so much resemblance to seasonal accumulations.

The "primary" shaly character of these muds is due to these laminations, but there is often shown an imperfect separation under impact which may be an expression of a tendency to minor lenticular segregation of the more limy from the less limy portions of mud in a sea in which limy deposits were contending with argillaceous material, but in which there was always more or less admixture of the two. Many of the laminations in the beds so distinguished are of rusty brown color, in which they resemble the more siliceous bands interbedded with the shales.

Over the eastern part of the island the rocks which have been mapped as "Utica" probably include some beds which belong to the "transitional series." The rocks at Allen Point may be such.

North of South Hero station, in the railway cut near the overhead bridge, are outcrops of rock much like that north of Rockwell Bay, and similar rock occurs just east of the station along the main highway. The beds in these outcrops have not been much disturbed from the horizontal and in the railway cut on both sides the dip may be plainly observed at an angle of about 15 degrees easterly. The rock is sheared, giving a splintery structure.

Again, along the road from South Hero station to Sandbar Bridge, a mile east of the station, some of the low-lying ledges seem to be sheared limy rocks like those of the cut just mentioned.

Towards Sandbar Bridge the rocks are blacker and more shaly. It would, therefore, seem that there is a gradation eastward from the basal Trenton through a "transitional series" to blacker, more shaly rocks like that which with some interruptions may be traced along the west shore of the island from Rockwell Bay northward.

Cedar and Fish Bladder Islands. These islands were visited with a suspicion that they would be found to be made up of the shale formation; but as they would serve to carry the inspection of the lake rocks eastward towards the Vermont mainland it was kept in mind that possibly some overthrust rocks might be found. There was seen no evidence of any kind to indicate that at the present time the slates of these islands have any traces of older rocks lying on them.

On these small islands the rocks which are shales are exposed in high cliffs around their shores, but are concealed by clay over their central portions. Savage Island was not visited. The Vermont Report shows it to be composed of the shale.

The rocks of Cedar and Fish Bladder Islands are entirely similar, and are laminated muds with firmer layers, such as have been described. Recognizing in these laminations a primary character it is clear that the beds of these islands have been terribly jammed and mashed, and distorted in the most amazing manner. The deformation is largely that of fracture; once continuous layers have been broken into chunks which have been separated from each other and mashed together, producing a sort of brecciation. Cleavage is also pronounced. At some places it appears that small blocks have moved over other parts of the formation, but such displacements were never very extended.

Kibbie Point. At Kibbie Point on the main island are rocks similar in their several structural features to those south of Sandbar Bridge and those of the islands just described. Distortion and shearing are plainly manifest. At this place a minor thrust was noted which did not appear to pass beyond the immediate exposure involved.

Robinson Point. At Robinson Point, four miles north of Kibbie Point, in the northeastern part of the island, the laminated shales are apparently not so badly mashed as in the southeastern part. They are disposed in rather gentle folds as can be determined from the laminations, which are usually the only means of identifying the stratification. The bedding is very often obscured by cleavage. This cuts the bedding at different angles as a consequence of buckling which preceded the shearing. At Robinson Point the stratification dip is about 15 degrees westerly, while that of the cleavage is 60 degrees easterly. Shearing has often produced a rough jointing which might be mistaken for bedding.

It is, however, uneven, giving a ragged, splintery structure. In many places bedding and cleavage dip in the same direction, although the two dips do not coincide in most cases.

In common with all the areas in the lake region the northeastern part of this island shows at some places local disturbances of the slate by folding and minor crushing, but these particular features are not so marked in present exposures in this part of the island as at other places.

Occasionally in these rocks one of the firmer siliceous beds will be seen to have buckled into gentle, wavy folds, while the laminated muds above and below show no apparent folding, but instead a more or less prominent cleavage induced by the same pressure that folded the firmer band. This is but one instance of the ease with which the shales accommodated themselves to pressure by shearing.

Calcite veining is very common among the shales in the eastern part of this island and sometimes indicates mashing when such is not very apparent from any other structures.

As well seen in cliff exposures the way a mass has behaved under shearing stress, even when bedding structure is largely destroyed, affords a means of telling whether the rocks were originally shaly or somewhat more massive. The more thinly-bedded rocks will give a slaty or finely splintered rock, while the thicker beds will be coarsely splintered, or sometimes roughly jointed.

A rather careful inspection of Grand Isle, joined with an examination of the rocks of North Hero, Alburgh peninsula, Isle La Motte, some of the smaller islands, and the Vermont mainland, shows that the Ordovician rocks of the Champlain basin, above the Beekmantown, are well represented on Grand Isle, and that some of the shales belong in the higher portions of the shale formation. On Grand Isle fossils from these higher horizons are rare, probably largely because of shearing; but in lithological characters the rocks are closely comparable to and seem susceptible of indentification with similar rocks in the upper part of the shale formation in many of the other parts of the region as named above.

The shore sections of the islands and the rocks along the mainland from the Canada line to the southern limit of the lake show that the various submerged channels, passages and bays that now form the basin known as Lake Champlain are practically throughout excavated in the softer rocks belonging to the transitional series of limestones and shales or to the higher black shales of the basin. But on both the islands and the mainland, sometimes forming parts of the present lake shore, are areas of older and very different kind of rock whose relations to the shales form some of the problems of the region.

Structure of Grand Isle. Certain apparently possible interpretations of the structural relations of the rocks of Grand Isle were discussed in the writer's first paper in the light of such studies as it had been possible to make up to the time of its publication. Attention was directed to the secondary structural differences shown by the rocks of the island. It was pointed out that a large portion of the formation including the transitional series and overlying black shales might be somewhat sharply differentiated from the massive strata of Beekmantown and Chazy ages. The deformational features shown by much of the transitional and shale series were noted and it was indicated that in the crushed condition of these rocks, now manifested by minor folding and tilting, minor reverse faulting, mashing and coarse brecciation, and different modes of shearing, they stand in contrast to the more massive strata of the island. The Beekmantown and Chazy beds were shown to have a generally flattish position in most of their exposures, particularly in the western half of the island, and not to be notably sheared, although somewhat deformed by pressure along or near their eastern margins. The Black River and the basal Trenton beds making up the ridge that has been described above, were also shown to lie rather flat, although the latter were described as showing minor buckling and shearing at some places.

Before passing to the discussion of the possible significance of the structural differences shown by these Grand Isle rocks as the result of differences in behavior under dynamic stresses it may be worth while to consider other differences of secondary character which some of them show.

The Beekmantown and Chazy rocks give an impression of having suffered certain alterations before the formation of the younger beds. The features referred to do not seem to represent on a minor scale or to be in the same class with those which in similar rocks of the region have more or less clearly been due to dynamic pressure, which in addition to producing metamorphism by crystallization also caused flowage and cleavage in different degrees, with the formation of marble or marbly rocks. The particular alterations mentioned appear to be due rather to static metamorphism of the rocks. As has been mentioned, they are apparently largely of the nature of granulation which has more or less completely changed the original material and produced a tough rock from which fossils are extracted with much difficulty. In some parts of the Champlain region rocks which have thus been altered have also been changed further by dynamic metamorphism and in such cases, of course, the earlier alteration features are blended with those of later date or are quite concealed. Gradations occur. In those rocks not much affected by dynamic agencies the fossils retain their outlines more or less perfectly, although crystallization may have destroyed details. In other rocks

the features resulting from static metamorphism are very evident, but other characters resulting from shearing stress appear in the shape of distortion of fossils and flowage or cleavage. In still other rocks, pressure has more completely obscured the older static features with the destruction or almost complete obliteration of fossil remains.

On Grand Isle the metamorphic characters of the Beekmantown and Chazy rocks appear to be due chiefly, if not wholly, to static changes. Absence of shearing, lack of distortion of fossils, apparent absence of mass deformation by folding and other features all point to such conclusion. If these rocks generally had suffered any internal deformation they should give more evidence of it, comparable with such as is found in other and similar rocks of the region, some of which are clearly of similar age while others probably are. Such deformation as these rocks may have experienced probably involved extensive mass dislocation, rather than what might be called internal adjustment, except as the latter was locally developed at some places.

The static alteration features of these massive, granular limestones give them an appearance of antiquity in contrast with the rocks with which they are associated. In the Black River and basal Trenton beds there is not present apparently the same degree of alteration by granulation as the Beekmantown and Chazy beds show. In these differences there is offered an indication quite distinct from that which fossils show of a hiatus between the Canadian and Mohawkian of the Champlain region. One is tempted somewhat to speculate on what the conditions were which led to the induration of the older rocks.

As was discussed in the first paper it has usually been assumed that there has been no great amount of lateral disturbance of any of the formations now found on Grand Isle, that the various rocks, including the masive limestones of the Beekmantown and Chazy formations, rest now substantially where they were formed. Unfortunately, the conditions on the island at the present time do not allow of positive determination of the relations between the massive limestones and the younger rocks. It was not possible to find any contacts of the former on the latter anywhere on the island. The idea that there has been displacement of the rocks of the island rests upon the considerations that such kind of deformation is widely prevalent in and characteristic of the region and that the rocks of the island show the effects of profound pressure.

It was first supposed that the shale formation of the whole region had undergone more severe folding as a whole, than now appears to have been the case, even in the eastern portion of the basin where the pressures might reasonably be assumed to have been more powerful. The comparatively small number of

exposures which it had been possible to inspect when such a view was formulated seemed to indicate that the shales were usually disposed in rather large close folds with overturning and consequent isoclinal structure. For places where the shales had clearly been overridden by older rocks along thrust planes they were discussed and pictured as having a prevailingly easterly dip, which was attributed to overturning. The conditions noted in a more extensive study of the region and from an examination of the shale formation in widely separated localities contradict such a view and have afforded data for a revision of ideas.

Any severe buckling or folding which the shales show now seem to be more or less local corrugations which pass along the strike into crush zones or fault fractures, or perhaps eventually into relatively gentle flexures marked only by a profound cleavage. Across the strike also these localized zones of severe folding, fracturing and mashing will apparently pass into gently undulating folds. Eastward toward the areas of the region marked by overthrust of older rocks on the shales the latter are more generally crushed and tilted, but at some places not far from the present margin of overthrust rocks they are notably flat, as indicated by bedding and laminations, although when flat they are always strongly sheared with the development of fracture cleavage.

What then are some of the conclusions to be drawn from the flat position or, generally speaking, open folds which these different rocks show, perhaps having Grand Isle principally in mind at this point? These rocks have clearly been acted upon by powerful compressive forces. This is shown on Grand Isle, but more clearly at other places. In the absence of any folding of large dimensions, or even universal close folding of small dimensions, the inference is strong that these rocks yielded to pressure chiefly through shearing of one kind or other. In this particular the massive limestones behaved like the shales; but in the former the shearing did not always manifest itself as an internal deformation with the development of fracture cleavage or other pronounced internal structure attributable to pressure, even when the associated shales often developed such structures to a high degree. On Grand Isle the massive strata have clearly effectively resisted any appreciable internal deformation for the most part. If this is not the correct interpretation it is not only difficult to understand their own characters but also why the much less massive, thinly-bedded, basal Trenton beds in west part of the island have not been more severely deformed in all ways. The massive beds have acted as a buffer for the younger rocks.

What then has probably been the behavior of the massive strata under pressure if they have not buckled or sheared with any visible flow or fracture structures? They are probably to be thought of as having moved as a great block or as blocks frag-

mented from the main mass with which they were once joined. They have resisted internal deformation in some places, as on Grand Isle, without, however, being able to prevail completely against the pressure. They were competent against such deformation as the shales exhibit, but not resistant enough to remain in place. From a consideration of the very different primary characters of the heavy limestones and the shales it is not difficult to see how forces competent to crush the shales might leave the massive limestones practically free of such features, but since it is apparent that the shales could hardly have been so generally crushed or sheared without diminishing their original breadth from east to west to a marked extent, it naturally becomes a question of how the massive rocks accommodated themselves to the simultaneous action of the same forces. That accommodation was reached in some places in the lake region by shearing even in the massive limestones is shown in numerous cases, but on Grand Isle it was effected chiefly by mass dislocation.

In the writer's first discussion of the probable structure of Grand Isle (see first paper) some of the considerations developed above were dwelt upon, but a good deal of stress was put upon present conditions among similar rocks in other parts of the Champlain region, particularly along the lake shore farther south. In Shoreham and Orwell the present field relations leave no doubt that older formations have ridden over the shales along thrust planes, and while at many places the massive beds have been somewhat folded and fractured and sometimes internally deformed, there are other places where the massive beds lie nearly flat with little evidence of internal changes resulting from pressure, although the rocks may be altered by other processes as is the case on Grand Isle. The so-called "Potsdam" and "Beekmantown" at Mt. Independence in Orwell and at Mutton Hill in Shoreham are cases in point. The conditions in other parts of the Champlain basin also give support of very positive character to the conclusion that massive Lower Ordovician beds similar to those on Grand Isle have been moved by thrusts and are not now in their original places.

In some studies which the writer made in the Hudson valley region near Poughkeepsie, New York, among rocks which in spite of their apparent remoteness from the Champlain basin have much resemblance to certain strata of the basin, not only in respect to age and general lithology, but in character of deformation as well, there seemed to be acceptable evidence for the conclusion that massive limestones of Lower Ordovician age had been thrust through younger shales by reverse faulting, often with a horizontal component powerful enough to drive the massive rocks in a lateral direction over the younger beds for a considerable but usually indeterminable distance.

While reverse faulting was recognized as probably playing a part in the disturbance of the rocks of Grand Isle, so that they are probably to be regarded as crowded somewhat by blocks riding against other blocks, the view was rather favored (see first paper) that the Beekmantown and Chazy beds, and some of the younger rocks as well, had been moved along a "major" thrust plane that had sheared beneath them after they had been broken by earlier reverse faulting and had transported them, perhaps for a long distance, from the east. They were thought of as having ridden over the shales that form the eastern part of the island, as well as others which intervene between the island and the Vermont mainland. Largely on account of normal faulting that probably occurred subsequent to the action of pressure on these rocks it is not now possible to decide whether this view is correct, or whether the massive rocks have simply broken through the younger beds and perhaps have travelled only a short distance over the shales which are now concealed beneath them. In this connection it should perhaps be remembered that we are dealing with an eroded and a sunken region.

From relations which are present in the Taconic hills of Sudbury and Orwell it was conjectured that a major thrust, like that referred to above, might have cut in such way as to carry early Cambrian strata at one place and early Ordovician at another over the shale formation. The conjecture rested in part on the assumption that early Ordovician beds lay unconformably upon eroded Cambrian rocks. The conditions in the Taconic hills are very puzzling and require further detailed study with reference to this point, but there remains little doubt of the existence of thrusting in the Taconic range. In the range the difficulty is to account definitely for the remarkable present distribution and contiguity of what appear to be Lower Cambrian terrigenous rocks and certain limestones including probably lower and middle Ordovician rocks.

The absence of large folds in the various rocks of the Champlain basin does not seem to fall in with a view that these formations were at any time elevated into mountain masses by huge and extensive plications of the crust. But the absence of large folds does not militate against an idea that there may well have been a considerable elevation of the rocks at some time in their history. That much elevation was possible seems to follow from consideration of the result of integrating a large number of thrusts of all dimensions, including those which now find expression in cleavage. The statement that there has not been extensive folding on a large scale is in accord with facts observed in the field. Lack of such folds in the shales seems to have been the direct result of failure to fold on the part of the massive beds which underlay them. But if the latter were thrust into the shales in varying degrees, sometimes into them, sometimes through them

and sometimes even over them, the effect apparently would have been to produce the crushed characters which they now show and to give a prominent fracture cleavage, whether the shales remained practically flat or were previously buckled into small folds or jammed into crush zones. The massive rocks are in the position of overthrust with reference to the shales that lie on one side of them, and of underthrust with respect to shales that lie on the other side and above them. Either relation seems sufficient to account for crushing and shearing of the shales.

On Grand Isle then different masses of rocks are probably to be thought of as now in more or less displaced relations with respect to one another as the result of compression. But the evidence on Grand Isle itself is inconclusive. Features elsewhere in the region that show what the actual behavior has been and what the tendency obviously was must be invoked and the probable presence of a common plan of structure for the region must be recognized in explaining the structure of Grand Isle.

It may as well be stated at this place as elsewhere that so far as observations have gone on the Vermont side of Lake Champlain, there is no evidence to show a thrust plane cutting beneath all the rocks now exposed in the Champlain basin. If such plane exists, perhaps evidence for it would hardly be sought on the Vermont side. There may be such a plane cutting at considerable but unknown depth and having its line of emergence in older rocks on the New York side of the lake. On the Vermont side the thrusts of various magnitudes which cut the rocks along the general strike and which are repeated across it may be the surface expression of a deep-seated shear, but the major thrusts on the Vermont side cut above the weak shales of the region, and are themselves apparently modified by antecedent faults and thrusts of minor dimensions.

North Hero Township.

(Rouses Point topographic sheet.)

The township of North Hero comprises several small islands of varying dimensions and two larger ones which are joined by a narrow neck, a portion of which, known as the "carrying place," is flooded at high water. These various insular areas are all of low relief and are made up of the shale formation. As in the case of Grand Isle the most satisfactory exposures are found along shore.

While there are some minor variations in the bedded characters of the rocks of the North Hero islands they are prevailingly black, limy shales with occasional firmer bands and much like those of the northern end of Grand Isle, showing beds of different thicknesses with the more muddy ones distinctly marked by laminations, accentuated by weathering, which appear in rocks

that have been strongly sheared, as well as in those which have not. The firmer beds are composed of tougher, more siliceous material than the associated muds. On these low islands with visibly limited vertical range of beds the firmer usually rusty beds do not so frequently appear and are not such conspicuous members as on the Vermont mainland, where they serve as useful features for correlation. On North Hero, as elsewhere, these rocks are of monotonous aspect, although with respect to the degree in which they are now sheared and cut by cleavage they show conspicuous differences among their outcrops.

The rocks were examined primarily for their secondary structural characters. In their primary lithological features they form a fairly homogeneous mass of deposits of apparently uninterrupted sequence.

Professor Perkins in his description of these islands has given an accurate account of the distribution and other general characters which it is hardly necessary to repeat, except as it may be desirable to emphasize certain aspects that belong to a discussion of the geology of the whole region.

The prominently argillaceous nature of the shale formation comes out strongly from the manner in which its surface portions have weathered. In many places the shale may be seen to grade upward into clay which retains the primary laminated character of the original rock. While the surface material of the islands is apparently to a considerable extent of glacial origin, much of the clay is purely residual material which has probably been largely formed since the glaciation of the region. Such material is apparently nowhere very thick.

While the shales have clearly buckled locally under pressure and almost always show cleavage well developed, they are apparently more commonly disposed in gentle swells of moderate lateral extent and comparatively small vertical displacement so that the bedding has low easterly or westerly dip and the axes of the folds lie horizontally or more often have slight northerly or southerly pitch. Such features are of interest with respect to the deformational history of the region, particularly with reference to the question of the extent of the region involved in the folding which is supposed to have occurred at the close of Ordovician time.

Studies made on North Hero seemed to show that the shales are more severely jammed along certain north-south belts than along others and that even shearing as expressed by fracture cleavage shows similar geographical segregation and is more marked in some places than at others even on the same meridians. Fossils are not uncommon in parts least sheared, so far as fossils are apparently present in these rocks; but where shearing has been severe, as might be expected, fossils are hard to find.

Some of the outcrops of the shore sections may now be briefly described.

On the island that lies just north of Grand Isle the rocks along shore between Grand Isle bridge and City Bay lie generally in a flattish position, from the bridge northward for a distance of about two miles, pitching gently to the north and then changing to an equally gentle southerly pitch. Whether the rock throughout the distance mentioned all belongs to the eastern limb of a common anticlinal fold is not certain. The dip is predominantly easterly, but where the pitch changes to southerly, about a mile south of City Bay, the rocks appear to be more broken by rough compression "joints" and shearing planes than farther south. At several places graptolites, probably *G. quadrimucronatus,* and heads of *T. becki* were found.

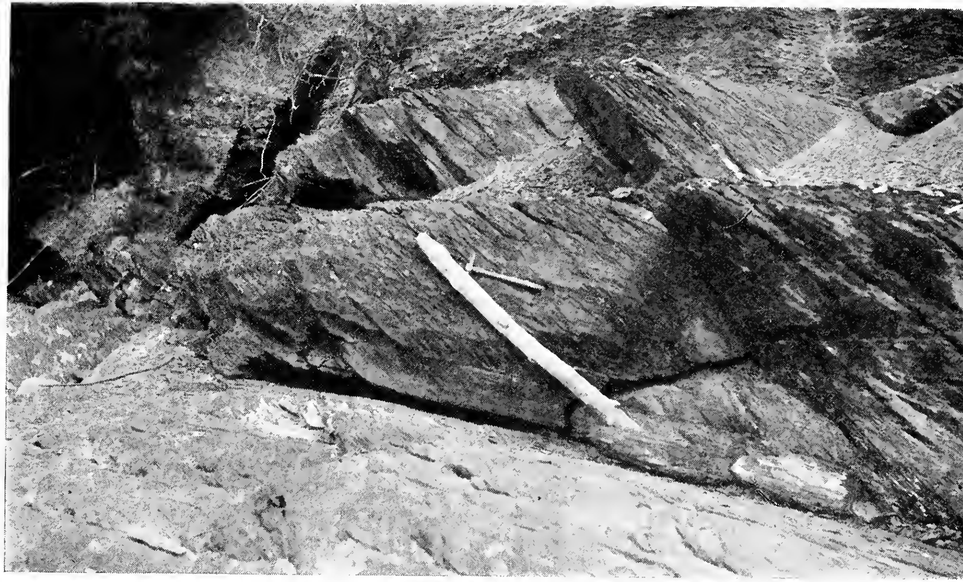
Along the west shore of this island similar variations in direction of pitch were noted; at Hazen Point the shales pitch southerly, less than a mile to the north they pitch in the opposite direction. In traversing the west shore one walks diagonally over small, gentle anticlinal and synclinal folds. At Hazen Point the dip is westerly, a mile north and nearly on the same meridian the dip is easterly. Farther north, about midway of the shore, the dip changes to westerly. Cleavage is usually well developed along the west shore. It did not appear that one type of fold was more marked in this regard than the other. In some places the folds are quite symmetrical, but in others they are less so and sharper and the beds are tilted to a high angle or even to a vertical position, and are sometimes overturned. Mashing and fracturing of beds are common in the sharper folds and most of the anticlinal buckles show some modification from crushing. Usually these crush zones are further marked by veinlets and streaks of calcite. Differences with respect to the expression of shearing may be correlated definitely with primary differences in the characters of the beds. In both easterly and westerly dipping beds a sort of jointing practically perpendicular to the bedding and parallel or diagonal with the strike was occasionally noted, especially along the shore of Pelot Point peninsula. This type of fracture is probably also an expression of shearing strain. Plates XIX and XX serve to convey ideas of the nature of some of the structures more clearly than verbal descriptions could. It seems as though folding and fracture sometimes preceded the formation of cleavage, as though the latter were the final expression in such cases of the shearing stress. Probably, however, these respective deformations were sequential in the same episode.

If it were assumed that there was considerable lateral variation in the characters of the beds of this shale formation, it is not difficult to understand that at some places along the same general meridian the rocks were mashed or broken by faults of small displacement and that at others sufficient relief came from frac-

PLATE XIX

Strongly folded thinly-bedded, argillaceous limestones of so-called "Utica" age, on west shore of North Hero island, about one-half mile north of North Hero station. View looking north.

PLATE XX



Sheared thinly-bedded laminated shales on west shore of North Hero island, about one-half mile south of North Hero station, showing nearly horizontal bedding cut by easterly-dipping cleavage and illustrating characters very frequent in the shales among the islands of the lake and on the Vermont mainland. The hammer marks the bedding planes and the log the cleavage dip. View looking north.

ture cleavage or compression jointing. These different types of deformation clearly belong to the same class or category and, probably, to the same general episode of disturbance.

Along the west shore of the island in many places where the rocks were not too badly sheared, graptolites and glabellas of *Triarthrus becki* were found. They were seen most abundantly just north of Hazen Point and along the shore of Pelot Point peninsula. Exceptionally low water in the season of 1921 allowed an inspection of practically the entire west shore section. South of Pelot Point the shales form bold cliffs which on foot are impassable except at low water. Possibly the rocks contain other fossils, but such were not seen.

The shale formation continues from the island just described to the one just north of it; but on this northern island much of the shore is very low and bowlder strewn, with no outcrops of the shale now visible. Good outcrops occur along the east shore in the southern part and on the west shore north of Blockhouse Point. These sections show the same kinds of rocks and fossils and the same structures as those found on the island just south.

Alburgh Peninsula.

(Rouses Point topographic sheet.)

The topographic and geologic features of Alburgh are quite like those of the North Hero islands. The peninsula is everywhere of low relief, only in two or three small areas rising above 200 feet. Several swampy tracts occur and some of these probably mark nearly or quite complete separation of the hard rock formation at the present water-level, so that if the surface material which now fills them were removed the peninsula would be resolved into insular or smaller peninsular fragments of the shale formation.

The rocks of Alburgh were examined over the interior of the peninsula at many places and for long distances where exposed along shore, but on the shore and inland there are many stretches and areas where the shales are not exposed.

Along the east shore bordering Alburgh Passage there is an almost continuous outcrop of the shale. At many places between Wagner Point and Point of the Tongue the shales dip easterly at low angle with easterly dipping cleavage. On the west shore of the Point of the Tongue the rocks are much disturbed, like those on the west shore of Pelot Point farther south on North Hero. Near the point the rocks are folded into a fairly sharp anticline. Northward the beds of the western limb stand at a high angle of dip and still farther north are overturned with high easterly dip, with shearing in the direction of the bedding.

After a stretch of sandy beach the rocks outcrop again at Coon Point, whence, with a slight interruption at Palmer Cove, they continue practically without break along the shore of Isle

La Motte Passage, to within two-thirds of a mile of the toll bridge.

At the western end of "Sand Beach," at Coon Point, the shales form a gentle open syncline. This is followed westward by a smaller, unsymmetrical anticlinal fold and this by a small, irregular synclinal flexure, which is succeeded by a broader anticlinal swell and this in turn by a broken syncline whose western limb is crushed against an anticlinal buckle. All the deformational features appear to have been the result of compression. Some portions of the rock had apparently become wedged between others and confined, so that under continued compression there occurred some differential movement and offsetting giving a structure simulating step faulting as produced by gravitational tensional stress. The beds are not distinguished by strong cleavage.

At Coon Point, in fact, the rocks for the most part do not show pronounced shearing and the locality is an excellent collecting ground for fossils, particularly fragments of the trilobite, *Triarthrus becki*, which were seen here in abundance. Graptolites were also found.

In the section along the west shore north of Coon Point there are no especially noteworthy structures different from those which have been described. About two miles north of the point the rocks show prevailingly low westerly dip and carry fossils like those at Coon Point; a series of vertical joints with strike N. about 52 degrees east cuts the shales at this place.

Just north of the Alburgh end of the Isle La Motte toll bridge is a high cliff in the shales and the shore road cuts through these rocks. At this place the rocks are severely jammed and the laminated beds much distorted and broken, showing great disorder. The rocks are filled with veins and bunches of calcite. North of these outcrops the shore is low and bowlder strewn with few outcrops as far as Windmill Point. Between Windmill Point and Rouses Point ferry landing the shales carry graptolites and fragments of trilobites and dip westerly at a low angle without conspicuous cleavage.

Ruedemann[1] reports a list of fossils from alternating black, calcareous shales and black to dark gray impure limestone outcropping along the lake shore one and a half miles east of Windmill Point which leaves "no doubt of the Trenton age" of the beds.

---

[1] Twelfth Report of Vt. State. Geol., p. 97.

PLATE XXI

Black River beds resting by thrust on thinner beds of probably Trenton age which have been folded and somewhat crushed. East shore of Isle La Motte, south of William Hill's landing and three-fourths of a mile east of Isle La Motte village.

Along the road that crosses the peninsula one and a half miles north of Isle La Motte station and again along the shore road and the shore near Dillenbeck Bay the shales yielded only graptolites and *T. becki.* The same fossils were found at East Alburgh and at Alburgh Springs along shore and also in some outcrops along the road between Alburgh Springs and Alburgh, west of Mud Creek.

The prevailing rocks now exposed over the Alburgh peninsula are the black, laminated shales and the conspicuous fossils are graptolites, probably *G. quadrimucronatus* and fragments of *Triarthrus becki.*

Isle La Motte.

(Rouses Point topographic sheet.)

In its main topographic outlines Isle La Motte bears much resemblance to Grand Isle, of which it is also to a large extent the geologic counterpart. In its general low relief it is like the other islands of the lake and portions of the Vermont mainland. Its rocks were noted very early in the history of geological exploration of the lake region and have been more recently described and mapped by Brainerd and Seely and by Perkins. In the published descriptions of the rocks their outstanding deformational characters have been mentioned, but no definite attempt has been made to account for the secondary relations which the formations have to one another, nor to correlate the conditions found on the island with those found in other parts of the region.

Several days were spent in a careful inspection of the island and the following brief review of the formations, as well as the more particular account and discussion of the secondary features are based upon personal acquaintance with the rocks.

The formations on Isle La Motte include a small area of the uppermost part of Brainerd and Seely's Beekmantown, exposed chiefly along shore in the southern part of the island, a large area of Chazy, including parts at least of all three divisions as defined by Brainerd and Seely and having a combined thickness as measured by these observers of about 500 feet, a small patch of Black River of roughly determined stratigraphic boundaries, a considerable area of Trenton limestone, and three relatively small exposures of the so-called "Utica" shale. In some of their structural characters and in their geographic arrangement many of the rocks have strong resemblance to similar rocks on Grand Isle.

The Beekmantown of the main island (Cloak Island will be described beyond) is confined to the southern end known as "The Head." Its surface extent is relatively small, although its shore section is nearly a mile long. The top of the formation was

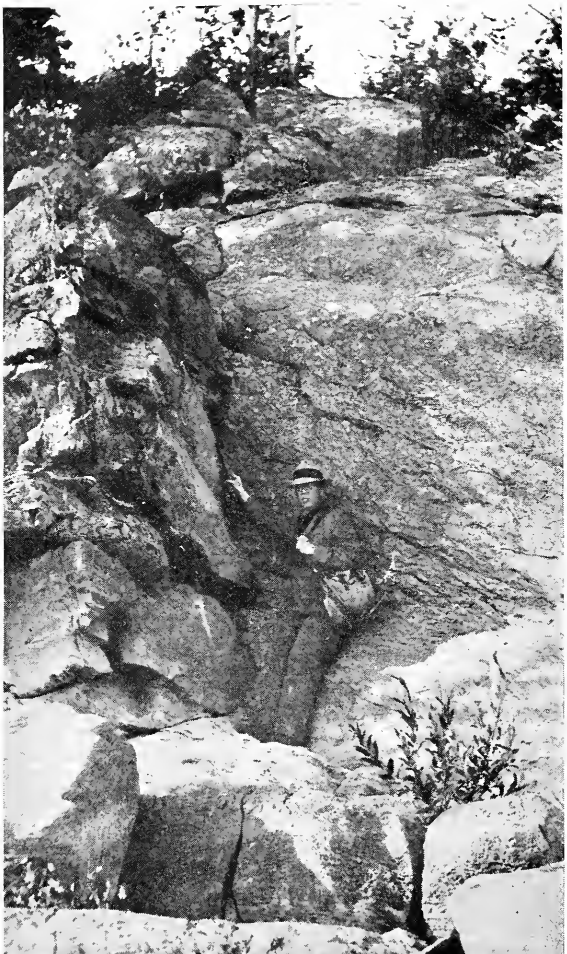
drawn by Seely and Perkins at a dark, compact layer about 30 inches thick which carries *Isochilina* and which is further characterized by breaking into large cubical blocks. The rest of the formation, as exposed to the limit of low water, consists of firm and shaly beds, varying in thickness from 6 to 30 inches. The rocks pitch in a general northerly direction at a low angle of about 5 degrees and are overlain by the lower Chazy. The generally flattish position of the Beekmantown beds and their lack of any shearing deformation are noteworthy features. Their primary characters have been sufficiently described by other observers.

The Chazy strata, which succeed the Beekmantown, have a similar flattish position, dipping at a low angle in a general northerly direction. Their present surface outcrops have a somewhat sinuous strike across the island. The vertical variations both among and within the lower Chazy beds are noteworthy, and there are horizontal variations shown in the rocks along shore, which are often accentuated by weathering, but which it is not possible to trace for any considerable distance inland. As a whole, the Chazy formation is impressive because of the massiveness of its beds. This massiveness appears to be at its maximum in the limestone members of the Middle Chazy. The portion of the Chazy regarded as forming the lower division, or Group A of Brainerd and Seely, seems to have a larger visible extent on the island than any other portion of the Chazy. The so-called Middle Chazy is, however, widely exposed. Outcrops of the upper portion are confined to a relatively small area on the east side of the island about midway of its length. The beds of this upper portion appear to pass westward beneath surface material, but outcrops are lacking to show how far it may extend.

About midway of its length the island is divided by a low, swampy tract of land, south of which except for a small strip of shale along the east shore, the visible rock all belongs to the Beekmantown or Chazy. North of this swampy land much of the island is under clay or drift which conceals the hard rock and in these areas the interesting features are the old marine clays, the sea beaches with their fossils and the drift. The drift may be partly an outwash from a readvance of the ice. In it occur numerous shallow depressions, now often pools of water, which suggest "kettles" formed by stranded blocks of ice. The Pleistocene deposits present a problem by themselves which the writer has made no effort to work out.

Over the eastern part of the northern half of the island the hard rock outcrops in many places and apparently belongs chiefly to the basal Trenton of the region. How far the members of this formation may extend beneath the surface covering to the west and north is a matter for conjecture. The Trenton rocks may be traced by their outcrops over an area about one and a half miles

PLATE XXII



Contact along a fairly regular and nearly vertical plane of faulting between basal Chazy with subjacent Beekmantown beds and strongly brecciated middle Chazy limestone, at the southwestern end of Cloak (Hill's) island, Isle La Motte. View looking north.

long and a mile wide. They reach the east shore in a few places, but are usually separated from the lake by narrow bands of shale or by the Black River. The Trenton rocks are rich in fossils and in this particular and other features are much like those in the western part of Grand Isle.

At the southeast, north of Clarks Bay, the Trenton beds are separated from the lake shore by a small band of Black River. There is nothing to suggest that the Black River ever had on Isle La Motte a much greater extension in its secondary relation to the other rocks with which it is now associated than it has at the present time. As a whole the Black River and the Trenton beds lie in a flattish position and are not extremely deformed.

The Black River and Trenton beds seem to show with respect to alteration differences from the Chazy similar to those which have been mentioned for Grand Isle. The rocks of Isle La Motte are clearly part and parcel of the series to which those of Grand Isle belong.

Structure. The various expressions now to be seen of the noteworty deformations of the rocks on Isle La Motte are to be found chiefly along or near the eastern shore. Description will begin with rocks at the southeastern end of the island.

The gentle northerly dip shown by the beds at "The Head" continues around the southeast shore, nearly to the small point south of Waite Bay. After an interval of about 100 feet of sandy beach there is shown an abrupt change of structure. The rocks at the point are greatly disturbed and brecciated. There seems to be an easterly dip, but from the clear indications present of severe compression this dip was interpreted as that of a rough jointing due to shearing and not as that of bedding. The age af the rocks is uncertain, but they are probably some part of the Chazy.

South-southwest of Waite Bay is Cloak Island. Although only a few acres in extent it possesses some very remarkable structural features. A mere inspection would leave no doubt of the fact that its rocks have been under severe compression.

The rocks are apparently mostly of Chazy age. A few fossils were found, including *Lingula limitaris* Seely, and a somewhat plicated brachiopod shell showing both valves with their markings. In the latter, although the beak was gone, other characters were well preserved. These with the decidedly gibbous outline strongly suggested *Camerotoechia plena. Maclurea* has been reported from the west side of the island, but was not seen by the writer. There may be present a small portion of the Beekmantown whose relations will be described presently.

In the eastern part of the island are massive beds which have clearly been folded and which at some places show westerly dip and clear N.-S. strike. But this mass deformation is masked by severe brecciation. The fragments of this badly crushed rock

vary in size from small bits to pieces two, three or more feet through. About midway of the island, east and west, and near the south shore, a huge block of house-like dimensions rests against the westward extension of the brecciated mass just described. In this block the beds stand on end with E.-W. strike. In them was found the plicated shell referred to above. This block or mass is followed westward by more brecciated rock and then occurs a somewhat detached mass of beds showing no apparent brecciation or shearing. This mass is perhaps 10 or 12 rods long from east to west and 5 rods wide from south to north. The beds in this mass all dip northerly at an angle of about 20 degrees. On the north they are cut off abruptly by a fault and rest along a more or less regular and nearly vertical plane (see Plate XXII) against coarsely brecciated rock similar in this respect to the rock described for the eastern end of the island. The lower members are much like some of the Beekmantown at "The Head" on the main island; they are rather thickly-bedded and often weather to a rusty color. Above these are other beds, perhaps in all about 15 feet thick, with some thin, almost shaly members. At the base of this upper portion in some sandy layers were found a number of fragments of *Lingula limitaris* Seely, which is thought to mark the base of the Chazy in the Champlain region. The northwestern and northern parts of the island are wooded and outcrops are not satisfactory for study. Along shore in these parts of the island the rocks usually form steep cliffs. On the west shore the rocks give the impression of big blocks jumbled together, but they are usually brecciated on a smaller scale as well. There are indistinct traces of folding and indications that in some places the beds stand on end.

The rather regular surface along which the conformable northerly dipping beds of the southwestern part of the island rest against the coarsely brecciated rock clearly marks a fault. It seems probable that the brecciated rocks are the younger; but what was the mode of deformation that brought these rocks into their present relations is far from clear. There seemed to be no indications of drag on any of the exposed edges of the conformable beds. The rocks of Cloak Island and those at the point just south of Waite Bay on the east shore of the main island give every indication of having been under severe compression.

Between the point described above and Waite Bay on the main island are some rocks that are apparently not much deformed. Then along shore is a short, sandy stretch which is succeeded northward by a beach of bowlders. Beyond this beach the hard rock outcrops along shore and continues to Holcomb Point. At some places friable layers have been cut by wave action so as to leave more massive layers overhanging. At other places the massive layers form the shore. South of Holcomb Point the rocks are probably all Lower Chazy. The layers are

not appreciably deformed. Similar rock occurs along part of the shore of the bay north of Holcomb Point and is succeeded by beds whose age was not determined, although they are probably part of the Chazy.

About 40 or 50 rods south of Jordan Point a small bay shows a narrow band of the shale formation, perhaps 300 yards long. The rock is laminated like that on the Alburgh shore to the east. The dip of the beds, as shown by the laminations, is prevailingly westerly, but the rocks are crushed. North and south along shore the shale gives place to limestone, and often the limestone forms the higher part of a bank which lower down is composed of the laminated shale. Search was made for a contact between the limestone and the shale and what appeared to be one was exposed by digging, but the relation was not decisive on account of the weathered condition of the shale. Along the shore where this band of shale occurs blocks of limestone have fallen down the bank apparently from the action of the waves upon the soft shale; but it is not necessary to suppose that the limestone lay on the shale.

The rock in the wooded pasture above the bank carries faint coils of *Maclurea magna,* and appears to be somewhat but not severely sheared. North of the bay along shore is massive Chazy carrying *M. magna* and *Girvanella.* These Chazy beds form a gentle sag pitching northerly just north of the bay and southerly near Jordan Point. The dip in general is westerly. But along this part of the shore the bedding often loses distinctness or is practically obliterated and the rock often appears as a crushed mass with fragments varying in size from small, angular pieces to big chunks. At other places instead of brecciation a shearing structure is developed across the bedding, giving an impression of easterly dip. The brecciated rock occurs at the southern end of the band of shale mentioned above and again north of it, south of Jordan Point. Its outcrops are not extensive, perhaps 75 feet in the southern exposure mentioned and 200 feet south of Jordan Point. This brecciated rock may be seen in contact with regularly bedded layers of some of which it may be a part that has been crushed. There has been some differential movement and dislocation, but how extensive it is difficult to make out. Perkins reported *Illaenus* and *Maclurea* from two separate fragments in the breccia. It is interpreted by the writer as an autoclastic rock. The undeformed beds with which the breccia is in contact seems to be Middle Chazy.

The low swampy tract extending from Clarks Bay just north of Jordan Point, westward across the island probably is a zone of fracture.

Just north of the eastern end of this swampy tract Black River beds form a band along shore, perhaps 125 rods long and 10 or 12 rods wide. The beds of this formation form a gentle

anticline at Hill's quarry, dipping westerly on one side at an angle of about 5 degrees and easterly on the other limb at an angle of about 12 degrees. Near the shore just east of Hill's quarry the surface of the rock shows many coils and opercula of a Maclurea, perhaps *M. logani*, and many small patches of sections of shells. Except for the *Maclurea*, which was not seen by the writer in the Black River elsewhere in the lake region, the rock closely resembles that which in many parts of western Vermont has been identified as belonging to this terrane.

For the most part the Black River beds are not marked by severe internal deformation; but at the northern end of the strip, at a small point a few rods south of William Hill's landing and perhaps 5 rods north of undisturbed easterly dipping beds, the rock is crushed with development of shearing (see Plate XXI). This structure may be best seen on the north side of the point just mentioned, where the thick layers of the Black River may be seen to form a subordinate anticline in which the roughly jointed, brecciated structure is particularly well shown. The bedding is obscured, but is still visible.

North of the crushed Black River beds the low bank and shelving shore are for a short distance in front of the William Hill place formed by Trenton beds. About 50 paces north of Hill's landing along shore are low ledges of a sheared, blackish rock which a few steps northward forms a sharp headland in which the lamination bands of the shale are clearly shown. The laminations dip at a high angle westerly, or are greatly broken and fragmented. The shale continues northward from the headland with the dip changing direction in the way so often observed on the islands lying to the east. If not mashed the rock is strongly sheared into a more or less fissile condition, and is often veined with secondary calcite.

Perhaps one-third of a mile north of Hill's landing the shale is interrupted along shore by a beach and then occurs a small mass of Trenton limestone which continues for about 200 feet. After another interval of beach the shale again forms the shore and continues along it for perhaps one-half a mile. Then the Trenton limestone outcrops again and extends to Cooper Point.

In all its exposure the shale forms only narrow strips on the shore, but in the most northern one the rock may be frequently seen in the bank and at one place it reaches across the shore road.

South of Cooper Point the limestone carrying Trenton fossils is at one place folded, overturned and broken and a part of the rock has overridden another part. At other places the rock shows westerly dip and at others lies nearly flat. North of Cooper Point the Trenton beds disappear under the shingle along shore. Around Cooper Point *Prasopora* is abundant, but much altered. Strong compression is manifest.

West of the outcrops that have been briefly described for the east shore, between the swampy tract and Cooper Point, the rocks exposed in the higher portions of the shore slopes, except for some Black River that has been mentioned, is all Trenton and the Trenton beds extend westward with numerous exposures through the fields to the main island road running through the village.

Away from the shore the Trenton beds exhibit less and less evidence of internal deformation and show a gentle northeasterly dip and northeast strike. The present topography of the pasture land between the shore and the main island road clearly displays the dip and strike of the beds as the land rises by terraces to the west.

In ascending from the shore to the higher ledges lying west of the camps along the shore road fossils appear, but there is an appreciable difference between these eastern outcrops and those that lie farther west with respect to the degree of deformation and alteration of the rock. At the east the beds show clearly more evidence of shearing strain, with subordinate mashing, although the westerly dip is usually discernible; the fossils are not well preserved.

The fossils in these Trenton beds west of the camps include the forms that distinguish the basal Trenton beds in the ridge half a mile east of the west shore on Grand Isle and the rocks themselves are counterparts.

To one who examines this island after a survey of the island of North Hero and the peninsula of Alburgh the scant occurrence of the shale formation on Isle La Motte is impressive. To one who may have been inclined to the view that the preservation at the present surface of broad areas of the weak shale formation, not only on the islands of the lake but also on the mainland, is perhaps due to a covering until rather recent times of a more durable formation which has been removed, the absence of any traces of rock that might have served for such protection anywhere on North Hero or Alburgh is also impressive. That such a covering does exist and probably has existed in some places in the lake region may be shown; but that all the shales had precisely similar thrust relations with massive limestones does not seem to have been the case.

But as has already been discussed for Grand Isle and for other parts of the Champlain basin the region is one eminently characterized by upthrust of older into younger formations. This mode of mass disturbance is widely prevalent and conspicuous, and dominates all others.

It has also been indicated that good evidence exists to show that subsequent to the great dislocations that piled the rocks against one another, normal faulting occurred by which the rocks were again fractured and displaced. It does not appear possible

in many cases of displacement, both along and across the strike, to say whether the dislocation was the result of compression or normal tension faulting. In the case of massive and highly elastic limestone strata it is possible to conceive that under compression the conditions might have been such as to permit a fracture across the strike that would produce relations simulating those that would result from normal faulting. In the absence of any positive criteria by which the exact nature of the differential movements between masses now clearly lying in displaced relations to one another may be determined, the explanation of such relations must rest upon probability.

The conditions on Isle La Motte are in so many respects comparable with those on Grand Isle that it seems that an explanation which would fit one would also fit the other, and the conditions that exist in other parts of the region are such that any interpretation which fits these two islands may probably be applied to the relations involving similar rocks at other places, with certain modifications.

The absence, so far as could be determined, of any traces of older limestones at the present time on the shales of North Hero and Alburgh stands against the view that these shales were ever covered by such rocks and that the massive limestones of Grand Isle and Isle La Motte represent downfaulted blocks of a much more extended mass of such rocks that was thrust over the shale and which has now largely disappeared by erosion. This distinctly does not mean that such limestones do not now and never did rest on the shales at perhaps many places in the lake region, or that shales may not underlie the massive rocks on Isle La Motte and Grand Isle. It further does not mean that the visible shales of the northern islands of the lake never lay at some depth beneath overthrust masses. The discussion applies to the relations among the visible rocks of these islands.

The field relations in the northern part of the lake region have not after careful inspection seemed to favor the idea of down-faulting of the shales among the older limestones through gravitational stress. The field evidence everywhere rather suggests that the present relations shown between massive limestones and shales, where the latter, as indicated by their younger age, occupy the downthrow side of a displacement, are the results of compression, in spite of the probability of normal faulting in the region and the lack of positive proof of thrust contacts. It is proper further to weigh the question as to whether the massive limestones of Grand Isle and Isle La Motte could have been thrust into and perhaps over shales and whether the field relations and various kinds of deformation lend themselves to such a view.

On the islands under discussion, there have not been found any positive surface traces of overlap of older on younger rocks. Some of the basal Trenton and associated Black River beds that

occur at the northern end of the ridge that runs east of the west shore in the lower western half of Grand Isle are older than the rocks along shore to the west of them and if normal faulting is ruled out the topographic position and attitude of the beds of the former fall in with idea of overthrust. Contacts are, however, lacking. The lake waters conceal the hard rock that lies to the west of the western shores of Grand Isle and Isle La Motte and whether the shales come to the surface beneath the lake is not known. Farther south in Shoreham and Orwell the margin of thrust overlap of the heavy limestones on the shale may be followed at the present surface, the shales lying to the west of the margin above the lake water level.

On Grand Isle, as has been described, the massive older rocks are more or less mashed and veined with calcite along their eastern margin. It is noteworthy that the more crushed and sheared condition of the massive rocks, both on Grand Isle and Isle La Motte, occurs along their irregular eastern margins.

A very similar condition has been noted and described by the writer for certain rocks in the Hudson valley.[1] Near Poughkeepsie, N. Y., massive dolomites and limestones have field relations to slates very similar to the relations shown in the lake region and which are plainly the results of the older rocks having been thrust into the younger slates. The older beds have broken both across and along the strike and in their eastern portions often show slickensiding and brecciation near their contacts with the slates. In the Poughkeepsie region, along their western margins, the older rocks may often be seen in contact with the slates into or over which they have been thrust. It is apparent from the generally flattish attitude of some of these overthrust rocks and the lack of deformation within them away from the brecciated zone along their eastern margins that they underwent little folding and essentially form great blocks that have been broken from an extensive formation lying at depth and driven upward. Although not equally manifest at all places a distinct horizontal component may usually be recognized in these displacements. Moreover, what sometimes appear now as reverse faults are probably eroded thrusts.

Taking the apparent absence of any traces of the massive Beekmantown, Chazy and Black River beds anywhere on Alburgh and North Hero at its face value, it is not reasonable to assume that the shales in these areas were overridden by a mass of the older rocks and that the older limestones of Isle La Motte represent a detached block of such an overthrust mass preserved by downfaulting. From the strong similarities which the secondary structural features in the northern part of the lake basin have to those of the Hudson valley near Poughkeepsie, it may not be unreasonable to suppose for each of these regions a similar

[1] New York State Bull. 148, 1911.

deformational history. The Beekmantown, Chazy, Black River and basal Trenton beds of Isle La Motte were broken from the respective masses to which they belonged and which lay beneath the shales and have under compression, through failure in any notable degree to accommodate through close shearing, moved up into the shale formation. By such deformation some portions of the shale would in some measure probably have been overthrust and other portions might be spoken of as underthrust. In both cases the shale would occupy the downthrow side. Along the plane of underthrust movement the relations produced might sometimes suggest normal faulting; but it is clear that displacement due to pressure would have involved differential movement between masses that were both under compression. The shales accommodated through cleavage and minor deformation, but the limestones refusing to do so moved as massive blocks.

If this interpretation is given to the relations of the limestones of Isle La Motte to the shales, it may be thought surprising that the limestones are not more generally present at the surface in nearby areas. But it is not necessary to suppose that such upthrust masses had in all cases the same amount of displacement with respect to the shales. Probably at depth the massive beds of Lower Ordovician rocks, and probably older rocks underlying them, have been variously broken and disturbed. The various kinds of deformation now to be seen on the eastern shore of Isle La Motte and along what was called the plane of underthrust bear out the idea that it was the massive beds which did the moving, so to speak. As is so frequently to be understood in application to faulting and thrusting, a plane is not to be thought of as a mathematical plane but rather as a zone of disturbance.

At some places it appears that the limestones along the underthrust side slid under the shales at a relatively low angle and at others ascended more nearly vertically. The massive rocks were all the while crowded against the shales and the crushed condition of the latter is in such wise not difficult to explain.

The thought has occurred that possibly the crushed condition of the rocks as described for the eastern shore of Isle La Motte and for Cloak Island was a character acquired within these rocks at depth before actual rupture and extensive bodily movement of ruptured masses. It certainly seems less likely that this condition was acquired during simple upward movement into the shales after rupture from the main mass at depth. The gradual transition westward from strongly deformed beds along the east shore of the island through those showing less and less strain to undeformed beds seems to indicate that differential internal deformation was followed by mass dislocation.

The relations and conditions on Grand Isle are in many particulars comparable with those on Isle La Motte and it seems

probable that the massive rocks of Grand Isle should be interpreted as upthrusts into the shale formation.

FRANKLIN COUNTY.

Highgate Township.

(St. Albans topographic sheet.)

General. The rocks of Highgate have long been known from the investigations of Logan, who worked out some of their important structural relations. While there have been some modifications with advancing knowledge of the age relations assigned to some of the rocks, the general conclusions of this able geologist have not been materially changed and his map, so far as it went, is accurate in detail of distribution and structure. The rocks of the township have been much disturbed and altered. Contacts are concealed and some relations much obscured by the mantle of surface material.

In Highgate rocks are found extending south from the Canada line along the lake shore and just to the east of it which are more or less similar to those of the areas just described or to some that occur near the lake farther south in Vermont, but some of these rocks are greatly altered. East of a narrow and somewhat irregular strip of such rocks are others whose counterparts have a great extension southward through western Vermont. Occurring among the latter are still other rocks which show features different from any of the others and present much difficulty in the definition of their age, in their correlation and in the explanation of their structural relationships to the rocks with which they are associated.

Between Missisquoi Bay and Rock River. Description will begin with rocks along or near the shore of the lake, south of the Canadian line.

Just south of the little bay at the village of Philipsburg, Province of Quebec, the shore is formed of black, slaty rocks carrying graptolites. These slates form a narrow, wave-cut platform and low cliffs for about a mile south of Philipsburg. Except for their greater alteration and more pronounced cleavage and disturbance these rocks are much like those of Alburgh and North Hero. They carry firm, siliceous bands, weathering rusty brown, which from their fragmented condition and scattered arrangement among the more shaly layers bear testimony to the severe crushing which these rocks have suffered. In their deformational features these rocks are much like those which will be described for the lake shore south of St. Albans Bay.

These slaty rocks are interrupted and replaced at places along the shore of the bay by great cliffs of massive-appearing limestones which often reach to the water's edge and are impassable

except by boat. At the bases of many of these cliffs are great blocks which have broken from them and over which one may sometimes scramble for considerable distances without, however, coming upon the slates. Working southward along the tops of these cliffs one comes to a small bay, a little way south of the national boundary, in which the slate outcrops. Slate was observed in the bank not more than 10 feet below the massive limestone which caps it, but the actual contact is concealed. South of the bay the limestone reaches the water and continues for many rods. Its margin then recedes somewhat eastward and clay or shingle forms the shore with the slates peeking through at places. Finally the slates pass from sight towards Rock River Bay.

The surfaces of the massive limestones which have been mentioned, in the extension of these rocks east from the shore through woods and pastures to the Highgate-Philipsburg road, were examined for fossils, but nothing definite was found. In these rocks, which are greatly altered, fossils have apparently largely been destroyed. In the shore cliffs these limestones usually appear very massive, but at some places beds of not very great thickness were observed. Sometimes a massive appearance seems to be due to a sort of welding of beds by shearing. Where bedding was observed it showed easterly dip at a low angle.

The calcareous beds exposed along and near the shore are largely gray, dolomitic limestones distinctly siliceous and often carrying chert, but away from shore these rocks pass upward into white, more or less marbly limestones whose weathered surfaces are often covered with a tracery of fine siliceous lines of lace-like patterns standing out in low relief. These whitish limestones outcrop along the Philipsburg-Highgate road from the national boundary to and across Rock River and form numerous exposures west of the road in the pastures and woods. East of Rock River Bay, both north and south of the stream, the white limestones were found in close association with the gray dolomites and a similar association was noted east of Highgate Springs; but at the latter place there is suggestion of dislocation and at one place of westerly dip which is a variation from the rather uniform easterly dip shown by the rocks south of the Canadian line, between the lake shore and the valley of Rock River.

A mile east of the shore near the Province line are indications of synclinal structure which becomes well-marked two-thirds of a mile north of the line. About one-fourth of a mile south-southwest of St. Armand station and one-eighth of a mile west of the railroad track, massive bluish-gray and yellow weathering beds dip at an angle of about 18 degrees to the northwest. These are succeeded westward and upward by massive-appearing rock carrying fossils, some of which resemble *Lituites*. This massive-appearing rock may be seen to be composed of relatively thin layers which have been welded into a thick stratum, as it now

appears. Some of the rock shows a striped appearance in which feature it looks much like similar rocks, which have been thought to belong to the Chazy, farther south in Vermont. A half mile north of these outcrops along the road from Moore's Corners to Philipsburg the striped rock shows southeasterly dip and westward is underlain by the bluish-gray and yellow weathering beds. The rocks in the western limb of this syncline are plainly sheared across the bedding, with the easterly dip of the induced cleavage at a higher angle than the bedding. There was observed at some places what was interpreted as a mashed structure as evidenced by blocks of the yellow weathering beds involved with the dove-colored or bluish rock. Westward towards the shore are found rocks like those which have been described as making up most of the surface between the lake shore and Rock River south of the Province line, and a generally low easterly dip is maintained in these rocks to their western margin. West from the axis of the syncline just mentioned, the succession across the strike in the limestones is probably from younger to older and older rocks.

These various rocks were regarded by Logan as parts of his Quebec Group, a name that now has hardly more than historic significance. There is still a field for careful work among these rocks with regard to their exact age and correlation and the details of their structure.

Brainerd and Seely seemed to recognize in the Philipsburg series of Logan most of the members of their Calciferous (Beekmantown) of Vermont with some beds that may be Chazy. The identification was largely on a lithological basis.

These rocks have not undergone extensive deformation by folding. They have suffered considerable shearing and great alteration from pressure and their relations to the slates along shore, than which they are unquestionably much older, is that of thrust which probably involved considerable lateral movement.

Along Rock River valley, south of the Province line, the rocks did not give much hint as to the extent to which they may have been brecciated along their eastern margins; nor was it possible to determine if transverse and longitudinal fractures are present among these massive limestones between the lake shore and Rock River valley.

In their lithological features and massive character these dolomites and limestones show more resemblance to the similar rocks of Benson and Orwell, which the writer has described in relations to younger rocks quite like those shown by the rocks of Highgate, than to any other rocks which he has seen. The general resemblance is very strong and seems to point to a widespread substratum of similar rock which was broken here and there and thrust through and over younger beds, in which relations they are now exposed.

Highgate Springs and vicinity. About one-half a mile south-southwest of the mouth of Rock River is Limekiln Point. The rock at this place is a grayish limestone which has been quarried. It is unlike the rock that occurs along shore north of Rock River Bay, and that to the east, north of Carman Brook.

Limekiln Point is separated by Phelps' Bay from a blunt promontory lying to the southwest of the Point. This promontory is the site of a former picnic ground. Over most of its western portion the rock is a sheared, impure, shaly limestone which forms low cliffs along the edge of the lake. These impure limestones yielded somewhat distorted fossils, among which some were sufficiently well preserved to warrant the following tentative references:

Rafinesquina incrassata (Hall); compare *Leptaena plicifera* Hall, fig. 1a, pl. 4 bis, Pal. N. Y. 1847.

R. incrassata, but larger than preceding, showing convex? valve with narrow and fairly deep depression extending from beak to margin, widening somewhat towards margin.

R. fasciata, comparable in size with fig. 3c and in detail with figs. 3a and 3d, pl. 4 bis, loc. cit.

The smaller specimen compared with *R. incrassata* has some resemblance to certain illustrations of the dorsal valve of *Plectambonites sericeus* (Sowerby), but differs in proportions, being shorter along the hinge line. The striae are also coarser, fewer in number, and of uniform size, with intermediate ones appearing near the margin. The specimen referred to *R. fasciata* is comparable with *R. alternata*, (Emmons). A gastropod of *Ecculiomphalus* type was also seen. The specimen was badly worn, but in spite of excoriation seemed to show, particularly near the tip, low, annular ridges. There was no visible angulation.

These fossils suggest that the shaly limestone may be of Upper Chazy, or possibly Trenton age. These limestones are flanked on the east by certain less sheared calcareous rocks that are in turn overlain by beds that resemble the Black River. Portions of the shaly limestones are less sheared than others, but most of these rocks under the hammer break into irregular pieces whose surfaces are suggestive of slight movements in the rock. In fact, the condition of most of these shaly rocks is substantially that of irregular cleavage or crushing.

The shaly limestones just described occur on the east side of the road running north from the Franklin House to the wharf on the second promontory southwest of Phelps' Bay, and about a half mile north of the hotel. In spite of shearing an easterly dip is apparent. These rocks are succeeded westward, on the west side of the road, by interbedded gray limestones and buff-weathering dolomites which are well shown at the end of the promontory. Flanking these limestones and dolomites on the west and apparently conformable with them are purplish or greenish-gray quartzitic sandstones in beds from 2 to 12 inches thick standing on end. The quartzitic sandstones are perhaps a hundred feet

thick. South and west they give place to younger rocks, from which they are probably separated by a dislocation. The sandstones form the western limb of a broken anticline. It is not clear just what the relation of the shaly limestones is to the interbedded gray and buff-weathering beds that lie west of them; they apparently lie above them.

The promontory bounded on the west by the sandstones is separated by a slight embayment of the shore from a small point at which occurs a series of very dark gray or blackish, thinly-bedded limestones which gave good Trenton fossils. In fossils and general lithology these Trenton rocks are comparable with the basal Trenton beds as seen on the islands to the southwest. They are folded and sheared. They grade into more shaly rocks which outcrop in the bank and along the beach below the camps southward until lost under the swampy land. Eastward above the bank in the fields among the summer cottages the Trenton beds are associated and folded with dense, black limestones of probably Black River age. These rocks continue southward, forming a ridge to the west of the Highgate-Swanton road. About one-fifth of a mile south of the hotel they form an unsymmetrical anticline with the Black River, forming the eroded crest and the Trenton beds the eastern and western limbs. On the east limb a reading gave the strike as N. 28° E. and the dip about 25° to the east. The Trenton rocks yielded typical fossils. On the west limb the beds dip at a high angle to the west or are overturned. About a half mile south of these outcrops and about on the same meridian a small ridge in the field west of the road shows the western limb of an anticline with the Trenton and Black River beds in inverted position. The Black River beds are from 2 to 3 feet thick and filled with small calcite veins, which, it may be noted, are frequent in all the beds of this formation around Highgate Springs as they are in many other places in western Vermont. The Trenton beds follow the Black River conformably on the west and dip at the same high angle easterly. The Trenton beds yielded crinoid stems and fragments of other fossils. Southward these rocks pass under surface material; the most southerly outcrop noted in Highgate occurs where the Highgate-Swanton road crosses the railroad track.

Directly east from the Franklin House, across the track near the mineral spring, beds carrying Trenton fossils (*Cryptolithus*) dip to the east. These outcrops are separated by a stretch of low, flat land about one-fourth of a mile wide from the massive limestones in the quarries of the Missisquoi Lime Works. To the south and southeast is an extensive sand plain under which the hard rocks are largely concealed. Just north of the Swanton line and a mile northeast of Swanton village, the road from Swanton to Highgate Center crosses a low ridge of dove-colored lime-

stone carrying patches of buff-weathering rock. These beds seem to be like those at the promontory at Highgate Springs.

Structural Features at Highgate Springs. In conformity with their less massive characters the various rocks around Highgate Springs have been much more deformed by folding than have the heavy dolomites and limestones that lie north and east of them. The folding is distinguished by a tendency to overturning on the western limbs and actual inversion of beds in some cases. Although now seen to be disposed for the most part in folds the relations in some places indicate dislocations. The Chazy rocks have ridden on the Trenton and the latter has probably been thrust against younger slates. Shearing structure in the form of brecciation or cleavage is to be seen in many of the rocks. The more massive rocks show fewer distinct marks of internal deformation.

Between the rocks at Limekiln Point and Highgate Springs and those lying to the east, north of Carman Brook, as well as those lying practically on the same meridian with the latter in the westernmost quarry of the Missisquoi Lime Works, there is an interval of surface material so that it is not possible to state what are the contact relations between the rocks lying at the east and those nearer the lake. But there can be no doubt that the massive rocks along the lake north of Highgate Springs rest on the slates by thrust and it is probable that the rocks at Limekiln Point and Highgate Springs are separated from the altered massive rocks to the east of them by a plane of thrust, and that the present sinuous western marginal outcrop of the rocks lying east of Highgate Springs and north of Carman Brook is essentially a continuation of the obvious margin of overlap of the similar rocks on the slates north of Rock River Bay.

According to this view, the folded, overturned and broken strata at Highgate Springs and those of Limekiln Point probably represent an aborted thrust which developed only to the point of release of other rocks by rupture. These other rocks might not be those which now form the surface east of the margin of overlap discussed above, but might be other rocks that are now covered by these thrusted rocks. Such a view depends upon the idea of repeated minor thrusts or reverse faults preceding other thrusts. Exposure of rocks younger than the massive limestones has not been accomplished east of the margin of overlap of the latter in this part of Vermont and all sections east of this margin gives a succession from younger to older formations, at least as far east as the eastern valley of Rock River.

An alternative explanation seems to be that the rocks at Highgate Springs and Limekiln Point may have ridden forward on the same major shear with the more altered rocks lying to the east and that the present trace of this shear at Highgate Springs is on the west of the rocks at this place. This, however, assumes

that a major shear cut minor thrusts and faults at depth and drove the truncated portions forward together. It is, of course, not possible to decide the point.

In every case where a marked dislocation occurred it is to be attributed to the more or less massive character of the rock and its reluctant behavior under powerful compression. The rocks behaved according to the elements of their primary structure. The heavy members moved as masses; the less massive accommodated by folding, crushing and shearing on a minor scale.

Northeast, east and southeast of Highgate Springs. Rock River has a roundabout course from its source to Lake Champlain. Its upper eastern portion flows northerly in a course roughly parallel with the shore of Missisquoi Bay and about three miles distant from it. The river crosses the Province line and about two miles north of it turns west across the structural axes of the hard rocks and then bends to a southwesterly direction to enter the lake.

Part of the rocks to be described under the above heading lie between the northward and southward courses of the river as it touches Vermont and the rest are found in the territory that extends southward and southwestward toward the Highgate-Swanton line.

Along the eastern margin of the valley of the lower (western) portion of Rock River is a modified escarpment in a series of interbedded, usually massive, siliceous dolomites, and quartzites or quartzitic sandstones, which belong to so-called Red Sandrock series, as this formation was named by the early geologists of Vermont. The western outcrop of these rocks, beginning at the Canada line, follows rather closely for a distance of about three miles the road that runs from St. Armand, P. Q. southward past Saxe monument to Swanton. For the rest of its course through Highgate the western margin is much less distinct and usually may be only approximately located from a few isolated outcrops emerging through the sand plain. The most western outcrop noted in Highgate was in a bed of quartzite at Kelly Brook, where this stream is crossed by a road one mile east of the Central Vermont railroad track.

Over the higher land north, east and south of Saxe monument the members of this series are well displayed. Outcrops are abundant along the roads and in the fields nearly to the eastern valley of Rock River, and the series was traced southward along the eastern edge of the sand plain through Carter Hill to a point just north of the St. Johnsbury and Champlain railroad and about a mile west of Highgate Center.

The members of the Red Sandrock series in Highgate form only a small portion of a great band of more or less similar rocks that extends for a long distance southward in Vermont. Even in rather widely separated areas in the northern part of the state

there is close resemblance in sequence and thickness of beds of this formation and in their colors, but in other places in Vermont the members of the Sandrock series, are seemingly represented by rocks which are apparently so unlike them that their common membership in the same formation is easily overlooked. Even within short distances, however, the members of the typical Sandrock series show appreciable horizontal and vertical variations in lithological characters and thickness of beds which come out in tracing the formation from place to place. At many places these rocks show much confusion on account of disturbances which have brought them into abnormal relations with other rocks; but leaving out dislocations it would not be possible to describe any vertical section which would hold in detail for any great distance away from the locality selected.

It seems probable from studies that have now been made in various parts of western Vermont, reckoning with the principle of lateral variation among rocks of the same general age, that ideas about the age relations of some rocks will have to be revised. It seems likely too, in view of deformations of the rocks, that estimates of the thicknesses of some of them will have to be modified. When the general similarity in field relations shown by very different looking rocks is appreciated even the absence of fossils in some of them may not stand in the way of recognition of the existence of a formational unit whose depositional and deformational histories have been much the same throughout.

In Highgate the members of the Sandrock formation require only brief description. It would require long and patient work to catalogue all the minor variations, which when done would largely represent wasted effort from our point of view. However, when the depositional history of the Lower Cambrian in Vermont is written it will mean that much attention will have been given to details of such kind.

South and east of Saxe monument are more or less massive quartzites, often weathering to a rusty color, apparently passing along the strike into reddish quartzites, and eastward across the strike, towards Saxe Brook, into whitish quartzites, all more or less regularly interbedded with gray, siliceous dolomites. The quartzites are all more or less calcareous or dolomitic.

North of Saxe monument are gray, dolomitic quartzites and siliceous dolomites passing eastward into flaggy quartzites. A gray, rusty-weathering, impure quartzite east of the St. Armand road and about 100 rods northeast of the monument gave recognizable fragments of the glabella, cheeks and pygidium of *Olenoides marcoui*. These were the only fossils found by the writer. In these rocks fossils come out only when the rock has weathered; but as experience will show not all weathered rock gives fossils, although it is probable that these are very common in the rocks.

Southeastward toward Highgate Center are brownish-gray quartzites and gray dolomites interbedded with flaggy quartzites.

In almost all the outcrops noted the dip is at a moderate angle to the east.

As a whole, these rocks probably make up a considerable, but as yet undetermined, thickness of Lower Cambrian beds, showing a rather uniform easterly dip and hardly any evidence of folding. The topography gives an occasional hint of dislocation; about one mile east of Saxe monument, east of Saxe Brook, a prominent scarp in massive quartzite probably marks a fault.

The rocks of the Sandrock series are unquestionably older than the massive limestones that lie west of them along and east of the shore of Missisquoi Bay. The only reasonable explanation of their structural relations is that which Logan advanced long ago; the Sandrock has been thrust against the limestones. Whether the thrust carried the Lower Cambrian any considerable distance over the massive limestones cannot be determined from the relations in Highgate. No contacts were found, but about a mile southwest of Saxe monument a quartzite bed of the Sandrock series is in close proximity to rocks of the lake shore series. Outcrops that were seen in the sand plain southeast of Highgate Springs show the margin of the Sandrock to be farther west than it is at the north.

In their deformation the Lower Cambrian beds behaved like the massive limestones to the west of them. While they probably suffered subordinate dislocations which are not now generally recognizable, they did not fold much but rather moved as a mass.

In their lack of folding the members of the Sandrock series in Highgate are in contrast to some of the similar rocks found farther south in Vermont, which are, however, when folded, in thinner beds. In their lack of this kind of deformation they are in accord with similar heavy beds elsewhere. The rocks behaved under pressure according to the elements of their primary structure.

In Highgate the Lower Cambrian series is nowhere in visible contact with the shale formation as it is farther south on the lake shore. But what the relations may be beneath the sand plain that intervenes between Highgate Springs and Swanton the surface covering effectually hides.

Eastern valley of Rock River. Along the eastern valley of Rock River, or low on the eastern flanks of the hills of interbedded quartzites and dolomites that have just been described, occur outcrops of rocks very different from the members of the Lower Cambrian series that bounds them on the west and from rocks that lie immediately to the east. These rocks show interesting differences among themselves from place to place and in the same outcrop, but have a general resemblance to each other

throughout and appear to make up a formational unit. They form the northern extension of the formation which includes the so-called "intraformational conglomerate," described by Edson for the towns of Swanton and St. Albans, and which he was inclined to view as of Middle Cambrian age. Logan showed these rocks on his map (Atlas accompanying Geology of Canada, 1863) as a band extending northward from Highgate Center across the Province line and as joining at the surface with his Quebec rocks in southern Stanbridge. Along Rock River these rocks as now exposed seem to hold to a fairly uniform width and band-like distribution, usually less than a mile in breadth across the strike and sometimes very narrow. Their representatives farther south are often more scattered and irregular in distribution.

This formation was traced to within a half mile of the Canadian line. At an exposure near the junction of the roads about a mile and a half east-northeast of Proper Pond are thinly-bedded, bluish limestones, whose outcropping edges along their strike appear as wavy bands on the weathered surface of the ledge. The limestone is associated with siliceous beds which lie on it and appear to be conformable, as though interbedded. Conglomeratic structure is not prominent, being confined to a patch about four feet square. However, the field was not exhaustively examined at this locality.

The valley of Rock River is more or less filled with drift and outcrops are intermittent. The next outcrops noted are one-third of a mile to the south, west of the road running parallel to the river. At this place the thinly-bedded, bluish limestone is intermingled with slaty rocks.

About a mile farther south, near the junction of three roads, are outcrops of sheared, bluish limestone, weathering to a dull gray. The rock is splintered and at places shows small dislocations which have completely severed the thin beds at numerous places.

Southward where the road crosses the river, in the bed of the stream, are sheared limestones now practically limy slates. The bedding is largely obliterated by the cleavage which dips easterly. The exposure of these rocks in the river bed may be 50 yards in breadth.

Above the river bank, southeastward, in a field east of the road, is a curious mixture of rocks which in general aspect are very like those making up several exposures in the towns of Swanton and St. Albans, to be described later. In fact the rocks at these several separated localities are counterparts, so far as lithological features go. The most conspicuous member is the conglomerate whose fragments range in size from small pieces to considerable blocks and are imbedded in a calcareo-siliceous matrix. The conglomerate portions are intermingled with other rocks, some of which are calcareous sandstones much like the

matrix of the conglomerate, and which sometimes weather to a reddish bluff, and others are slaty rocks like those in the river bed nearby. The fragments of the conglomerate are frequently bluish limestone and often sharply angular in section. There is much confusion and anything like orderly sequence was not discernible. There is visible shearing structure in some of the rocks.

A half mile farther south, where the road crosses the river, near Johnson's farm, is a gorge worn by the stream in dark, bluish-gray, finely granular limestone which yielded obscure fossils, too fragmentary for positive determination, including a tiny orthis-like form and several pieces of trilobites, all very small. The rock shows folding and shearing and some brecciation.[1]

Twenty-five rods southwest of the bridge at the last-named locality and west of the road, at a small ridge, are excellent exposures of the thinly-bedded, bluish limestones like those described for the outcrops farther north. The edges of the beds show a very conspicuous wavy arrangement and the layers show all stages of fragmentation or dislocation from incipient parting to rupture with varying degrees of displacement of broken parts. According to the writer's view, these are distinctly secondary compression effects, belonging in the category of brecciation, and not to be confused with conglomeratic structure which parts of this formation show. The angular character of the conglomerate fragments often gives a distinctly brecciated appearance to that rock in many of its outcrops and the fragments themselves often suggest broken-up, thin, limestone layers; but the principal structure of the conglomerate proper seems really to be primary, although the way it was produced remains a mystery. The conglomerate itself may show secondary shearing effects like some of those in the rocks associated with it.

Blue limestones like those in the ridge just mentioned continue southward on the strike and outcrop on the road going west, along which road after an interval of drift they are succeeded by the Cambrian dolomites and quartzites.

Highgate Center. In a cut of the St. Johnsbury and Lake Champlain R. R. one-fourth of a mile northwest of the village of Highgate Center is exposed a laminated bluish limestone dipping easterly at a moderate angle and cut by rough shearing joints which dip in the same direction at a high angle. The rock has weathered enough to bring out the essentially shaly character of the rock by the laminations bands which it shows.

The field south of the cut, above the bank, gives numerous exposures of the thin, blue limestones noted along the valley of Rock River. The beds sometimes stand at a high angle of dip and present the same wavy arrangement in the surface of the ledge. The limestones are intermingled with ledges of gray slates. All the rocks are greatly altered and without fossils.

[1] See supplementary note at the end of this paper.

Highgate Falls. At Highgate Falls the Missisquoi River flows through a narrow post-glacial channel which the stream has cut in a mass of jumbled rocks now exposed in its bed and banks. The section from the bridge to the final outcrops at the base of the falls is perhaps one-fifth of a mile long and practically cuts the rocks from east to west across their strike. The gorge lies about one-half mile south of the laminated, dark blue limestone and thin, lighter blue limestones and intermingled slates, described above for the locality just northwest of Highgate Center village, and about two miles north-northwest of the northern exposures in Swanton township of the thin limestones, shales and conglomerate which outcrop along the Highgate-St. Albans road.

In the upper part of the northern wall of the gorge just below the bridge is a massive looking stratum of dark, fine-grained, siliceous rock, twenty or more feet thick as now exposed, which may be seen to have suffered some shearing, and which as a whole shows little evidence of bedding. In the lower portion of this stratum is a curious "breccia" of small blocks of slaty rock, angular in section and imbedded in a matrix of dark, fine-grained material. About 75 feet below the bridge, in the base of the massive stratum, is included a large block of somewhat banded, coarse-textured slate in a piece of which were found two ill-preserved specimens of graptolites, tentatively identified by the writer as *Dictyonema,* probably *flabelliforme,* and *Staurograptus dichotomus* Emmons.

The occurrence of these bryograptoid forms at this locality is worthy of note. The specimens were submitted to Dr. Ruedemann of Albany. While recognizing their poor state of preservation, Dr. Ruedemann felt sufficiently sure of the general affinities of these fossils to write: "Even lacking a correct specific determination of the forms, it is safe to say that they belong either to the Schaghticoke or Deep Kill shales (Hudson valley formations) for the higher graptolite shales of the slate belt do not afford similar species." In specific reference to the opinion of the writer as to the forms to which these fossils might be referred, or with which they might at least be compared, Dr. Ruedemann wrote: "The fossil which you compare with *Staurograptus dichotomus* has indeed the general aspect and outline of that species. On closer inspection, however, it appears to be rather a young *Dictyonema,* flattened out in a vertical instead of a lateral direction. This conclusion is suggested both by the *Dictyonema*-like appearance of the thecae and the apparent presence of dissepiments connecting the branches. The fossil marked (2) is a fragment of *Dictyonema,* possibly of the *flabelliforme*-group, but also comparable to *D. rectilineatum* of the Deep Kill shale."

Dr. Ruedemann had no knowledge of the specific locality at which these fossils were found. His properly guarded and yet

reasonably confident judgment that they probably represent a Beekmantown horizon is of interest.

The question would at once be raised as to the probable extent at Highgate of the formation to which these fossiliferous slates belong. This it would be difficult to state. In the gorge the rocks change in lithological character within short distances. The particular block yielding the fossils seems to be somewhat isolated, although similar rock appears to form part of the river bed adjoining the wall of the gorge. The rock carrying the fossils gives place rather abruptly westward to the brecciated rock described above as forming the basal portion of the massive stratum and which also forms part of the river bed adjoining the wall.

The section passes vertically downward from the "breccia" into a mass of jumbled grayish-black, or sometimes bluish-black slates carrying firmer bands of yellow-weathering rock. The slates are strongly sheared and the included firmer bands are usually twisted or broken so that large detached, more or less rectangular blocks, as they appear on the surface, now lie in helter-skelter fashion among the slates, often oriented across the strike at various angles. The disturbances which the slates have suffered interfere with any reading of the dip of the bedding and the thickness exposed remained undetermined. Close inspection of the surface of the slate at many places reveals the presence of small fragments of slate very similar to their matrix, the whole so thoroughly compacted that the broken up condition is hardly visible except at close range.

Downstream the slates pass into a "brecciated" or conglomeratic layer 8 or 10 feet thick. This is followed by a succession of alternating, thin bluish and more massive grayish-buff layers dipping easterly about 18°, with a bed of the grayish-buff about 5 feet thick at the base, all distinctly sheared. This stratum may be repeated for it is followed by a similar series which is succeeded by a "brecciated" stratum about 30 feet thick.

The rocks which form the bank of the river at the lower, western end of the gorge were only casually inspected at the end of a day's work. No fossils were found in them.

Though a diligent search was made in its upper part, no fossils other than those mentioned were found in the gorge.

The section at Highgate Falls shows that the rocks forming the gorge have been under great compression and that some of them have been greatly crushed and sheared. It is not clear that the "brecciation" shown by the various rocks is all of similar origin. The fragmental basal portion of the massive stratum in the upper part of the northern wall visibly grades into the overlying rock in such manner as to make it extremely difficult to imagine just how it could be explained as due to friction or mashing during movement. While there seems to be some indication that the massive stratum has ridden over the beds below it, the

now thoroughly compacted "breccia" appears to be so related to the main mass of the massive stratum that if thrusting did occur the "breccia" could readily be imagined to have attained its present condition prior to movement.

The evidence of differential movement between the massive stratum, as it has been designated, and the black slates below it consists not so much in the identification of any distinct thrust plane between the two as in the contrast shown with respect to primary bedding characters and internal deformation. The crushing of the slates has been intense. It seems to suggest that they were crowded by a heavy mass above them which has partly been eroded. Perhaps they were also crowded from beneath. Data were not found to determine whether masses of very different age are involved. It is possible that most of the rocks belong to a conformable or disconformable series which behaved according to the nature of their primary structure. The block of slate in which the fossils were found has much the aspect of an inclusion caught up during thrusting.

Hungerford Brook. The road from Highgate Falls to St. Albans crosses Hungerford Brook a mile south of Highgate village. At the bridge and along and in the bed of the stream east and west of the bridge are blackish slates. According to Dr. Howell of Princeton, who has collected fossils from these rocks, but who wishes to study his specimens with care before announcing his final conclusion, these slates may be of Upper or late Middle Cambrian age. Dr. Howell bases his opinion in part on the reported discovery by the Canadian Survey many years ago of *Agnostus orion* at Hungerford Brook.[1]

Eastern Highgate. The rocks lying to the east of the blue limestones, slates and conglomerates along the eastern valley of Rock River were only casually inspected along the low ridge near the South Gore School and the road running from the school to Highgate Center. The rocks are slates of very similar and monotonous aspect and gave no fossils. They are associated with conglomerate at some places. It would require further study to reach any tentative opinion of the age of these rocks and their relations to the rocks lying to the west of them. They were mapped as "Georgia Slates" by the Vermont Survey.

Swanton Township.

(St. Albans topographic sheet.)

General. Swanton township is bordered by the lake on the west. It includes Hog Island, an essentially insular area joined to the mainland by the delta of the Missisquoi River. The township is bounded by Highgate on the north, by Sheldon and Fairfield on the east and by St. Albans on the south.

[1]Personal communication.

Hog Island. Hog Island, so-called, is the western extremity of a peninsula jutting into Lake Champlain. The designation of island is probably wholly correct with respect to the relation of the hard rock portion of the peninsula to that of the Vermont mainland; but the island and mainland are now joined by modified delta and flood plain deposits of the Missisquoi River which occupy a strip from two and a half to three miles wide, extending from Maquam Bay at the south to the eastern portion of Missisquoi Bay at the north. Over this delta surface the Missisquoi River now courses northward, in which direction it is extending its delta into Missisquoi Bay. The river enters the bay by three short distributaries. Three sluggish water channels, known respectively as Dead, Maquam and Charcoal Creeks, probably mark former distributary outlets of the river.

The hard rock is exposed along shore and in many low-lying ledges inland and apparently all belongs to the shale formation of the region. The rocks are everywhere so similar in lithology and structural features to those of Alburgh and North Hero that description would be largely repetition. Easterly and westerly dipping beds were noted and both were observed to be cut by easterly-dipping cleavage.

Northwest, west and southwest of Swanton village. The slates of Hog Island undoubtedly pass under the delta deposits of the Missisquoi River and the low sand plain west of the village of Swanton. There are few if any outcrops in the sand plain, but at some places along the roads the surface soil contains abundant chips of slate showing that the hard rock often lies close to the surface. The Missisquoi from Swanton village northward rarely cuts the slate above the surface of the river, as may be readily seen in passing along the road that closely follows the southwest bank of the stream; a considerable ledge was noted on the north bank of the stream about a mile north of Swanton Falls.

The slate outcrops at Swanton Falls in the western part of the village. The rock has the usual characters shown by the formation in its outcrops along meridians farther west, consisting of slates with firmer bands, the former highly cleaved and the latter bent or broken with small offsets. The slates are often graphitic and carry graptolites, which have retained their form but have largely lost their thecal structures. They seem to be *G. quadrimucronatus*.

The Missisquoi River makes a prominent bend to the south just south of Swanton village. Southwest and south of this bend is a wide expanse of lowland lying between the lake shore and a meridian passing just east of the village. The slate formation probably underlies this lowland throughout its breadth of three and a half miles to the St. Albans line. Away from the lake the slates are found only infrequently over the flat, sandy plain; but along the lake shore they are exposed from Hotel Cham-

plain southward. They are laminated mud rocks with firmer bands, marked by crushing and cleavage, and abundant calcite veining. The shore section gives the same lithological and structural features found in the rocks of North Hero three miles to the west.

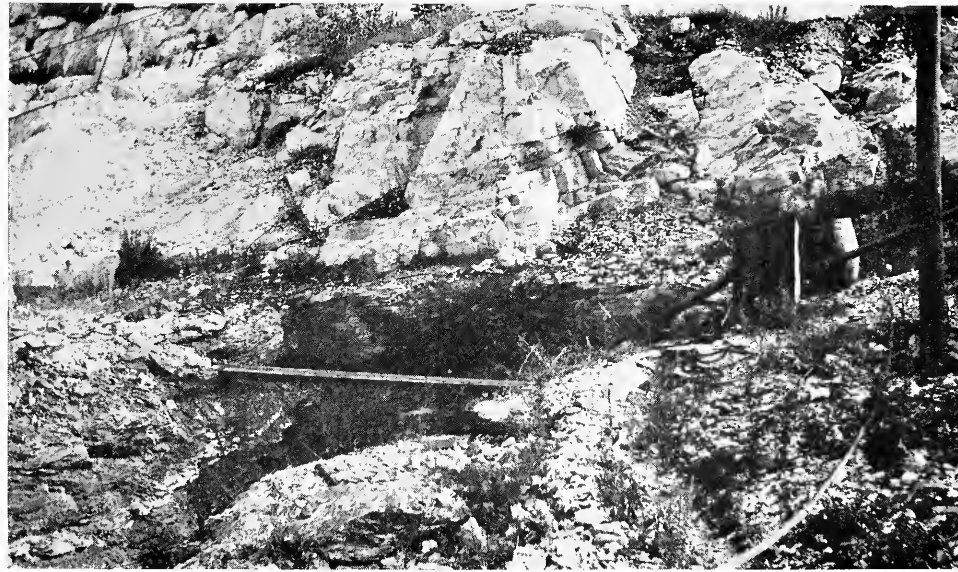
Between Swanton village and the Missisquoi River. Swanton village is situated largely on a sand plain. The only outcrops, except those at Swanton Falls, occur south of the main village between the road running from Swanton to St. Albans and the Missisquoi River.

The rock in the western quarry of John P. Rich (Swanton Lime Works) is a greatly altered, grayish-white, often somewhat marbly limestone and as exposed in the face of the quarry gives little evidence of bedding. In the southwestern part of the quarry, as exposed in the summer of 1921, the gray limestone was seen resting on black, graphitic, limy slate which is strongly sheared and filled with small veins of secondary calcite and quartz. In the slate a considerable hole had been dug apparently to see to what depth the slate extended. The photograph shows the general relations. See Plate XXIII. The slate is exposed over a small space in the floor of the quarry. Its presence served to drive quarrying operations in a horizontal direction eastward.

In an older quarry that lies to the southeast the rock is similar to that just described, but shows bedding more distinctly, with easterly dip. The gray limestone outcrops abundantly in the fields near the quarries. It is everywhere crystalline and barren of fossils. It extends eastward to the bank of the river, forming conspicuous ledges at the highway bridge. Southeastward and southward the rock either is not present or lies under the sand plain along the river. The whole mass of this limestone south of Swanton village as now exposed is about two-thirds of a mile in extent from west to east and two-fifths of a mile from north to south. It is now separated from all similar rock in the immediate vicinity by surface material. The nearest outcrop northward and the only one noted between this mass and similar rock east of Highgate Springs is about a mile east-northeast of Swanton village along the road to Highgate Center. At this place emerging from the sand plain is a low ridge of gray limestone associated with patches of buff- or chamois-colored rock which are probably parts of eroded layers.

The gray limestone ends rather abruptly west of Rich's quarry. The extent to which it overlaps the slate westward was not determined. It is probable that the slate passes round to the south of the limestone mass under the surface covering; for although not observed in the immediate neighborhood of the limestone, or along the river, about three-fourths of a mile to the southeast, slate like that in the floor of Rich's quarry has relation to gray limestone quite similar to that shown in the quarry. This

PLATE XXIII



Massive, crystalline, marbly limestone interpreted as resting by thrust on black, crushed slaty phyllite in the quarry of the Swanton Lime Works at Swanton village. View looking south at the Western edge of the quarry.

outcrop of the slate carries it to a meridian one-third of a mile east of the eastern edge of the limestone mass south of Swanton village, and about one mile east of the exposed slate at Rich's quarry.

Rocks south of Swanton village, bordering the eastern margin of the lowland. The slate at the last-mentioned locality is perhaps 20 rods east of the Central Vermont railroad track and a few rods south of the road which after skirting the southwestern bank of the Missisquoi passes eastward to join the Swanton-St. Albans road. The rock occurs in a shallow pit that has apparently been excavated for road material. Just east of the slate, gray limestone with some darker beds near the base and irregularly distributed yellow-weathering beds in the higher portions forms a hill just east of the slate. The slate and calcareous rocks were not seen in actual contact, but the space separating the two is small and there is no doubt that the limestone lies against the slate. Some of the limestone carries indistinct fossil markings; the rocks dip easterly and extend eastward to within about 250 yards of the Swanton-St. Albans road.

It was not possible to determine the horizon of the slate either at Rich's quarry or at the last-named locality; but there seems little doubt that it represents the slate formation of the lake region and that it is younger than the limestones with which it is associated. That there has been simple inversion of rocks due to folding and overturning seems extremely improbable, for it would then seem that other rocks should intervene between the slates and limestones, which is not the case. The reasonable inference is that the limestones rest by thrust overlap on the slates in both cases. The relations conform to the regional type of dislocation.

The limestones at both of the localities just described are probably of Lower Ordovician and possibly of Chazy age. This has hardly been proved by fossils, but is made probable by comparison with similar rocks in similar relations which will be described beyond.

About 50 rods south-southwest of the outcrops last described, west of the main line track of the Central Vermont R. R., in the angle formed by it and the Alburgh branch, is a low hill composed mostly of a schistose quartzite or quartzitic slate, apparently without fossils. Associated with this quartzite are somewhat isolated patches of bluish limestone in uncertain structural relations with the quartzite. In its thinly-bedded character and lithology the limestone has resemblance to certain rocks of Trenton age. It appears to be fossiliferous, but it is so altered that nothing distinct was obtained. Calcite veining is frequent. The limestone shows its bedding better at some places than at others and occasionally presents a wavy arrangement in the outcropping edges of the beds. It appears to have been caught up by the quartzite. The distribu-

tion of the limestone in the quartzite is peculiar. A conspicuous exposure occurs just west of the track. This is followed westward by quartzite and then occurs another somewhat band-like strip of the limestone which seems to be largely surrounded by the slaty quartzite. The dip of both rocks is easterly. It is suspected that the quartzite is repeated and that the limestone may also be. The distribution and visible structure thus gives a rough suggestion of interbedding, which however does not seem probable. The whole width of this hill from east to west is perhaps 200 or 250 yards. The rocks to the west of it are concealed.

About 100 yards south of this hill, and just west of the main line track a small outcrop of the schistose quartzite emerges from the surface covering in the low ground and just south of this is a small exposure of thinly-bedded, bluish limestone.

A third of a mile to the south of these last-mentioned outcrops, just north of Swanton Junction and west of the track, is another hill which shows a very different kind of rock. It belongs to the quartzite-dolomite or Red Sandrock series lying to the east, presently to be described. On the east side of the hill the bedding dips easterly at a moderate angle for the most part, but at the northeastern end near a small quarry, beds which dip easterly at a high angle lie against others with varying westerly dip. This hill shows a prominent scarp on the west, perhaps 60 or 75 feet high, with the beds apparently dipping westerly at a high angle. At the west the descent is everywhere abrupt to the surface of the low ground that lies to the west. No contacts with the rocks that lie beneath the plain were found.

South of this hill a private road runs westward across the plain to two farm houses about one-half mile west of the Junction. The houses stand on a low ridge, on the east side of which is a considerable thickness of rather heavily-bedded limestone, some of which is striped exactly like many exposures of the so-called Middle Chazy in other parts of the lake region. The beds of this series dip easterly at a high angle and have a sinuous strike with probable offsets. *M. magna* was not found, but a ledge just north of the barn gave numerous specimens of the characteristic *Girvanella ocellata* (Seely). These rocks are succeeded westward by beds of grayish-black limestone weathering to a lighter gray than the Chazy and possessing all the lithological characters of the Black River. They dip easterly like the Chazy beds and are full of small calcite veins. Fossils were not found. West of these, also dipping easterly, and apparently conformable with the Black River beds, are thinly-bedded, blue limestones of probable Trenton age. Crinoid stems, weathered section of shells and a much worn brachiopod were found with other indistinct fossils. The terrane is only partly represented.

These apparently conformable beds are thus seen to be overturned, probably on the western limb of an anticlinal fold, but pos-

sibly on the eastern limb of a syncline. The rocks in the plain, both east and west are concealed. The writer's notes record no siliceous beds in the Chazy at this place. The Black River seemed to be in conformable contact with the Middle Chazy limestone. This is a common association farther south in Vermont; but it will appear from later discussions that there are differences in the ways in which these associated formations are deformed at various places. The field relations at this place did not suggest any marked dislocations among the different members. As a whole, however, they are thought of as resting by thrust against younger rocks at the west.

A half mile to the south-southeast is the large mass in which the Fonda quarry is excavated. It forms a hill just west of the railroad track. The quarry has been sunk in the western slope of a massive, crystalline, gray limestone which forms much of the higher portion of the hill. Except for some blackish layers at one place in the floor of the quarry the rock has much the same appearance throughout and shows bedding imperfectly preserved, with easterly dip. The rock is very much like that south of Swanton village. South of the quarry on top of the ridge is a sort of "hog-back" of altered calcareous sandstone or quartzite, perhaps 200 yards long and 50 to 75 feet wide, which does not appear in the quarry and seems to be surrounded by limestone. East of this quartzitic rock is gray limestone associated with layers weathering to a pinkish buff, which approach close to the railroad track. East of the track is the Red Sandrock.

The ridge in which the quarry is located descends westward by irregular surface to the plain that extends towards the lake. The various rocks outcropping on the intermediate level west of the ridge have a confused arrangement. At the west are beds which are apparently to be correlated with the Chazy. The strike of these beds at some places changes as much as 90° within a few feet. They are associated with rocks having the markings of the Black River and veined with white calcite. Numerous outcrops of thin, blue limestones were noted in no very regular relation to the other rocks. The latter carry obscure fossils and seem to be of Trenton age.

The various rocks about Fonda's quarry have been much disturbed. They have probably been broken by thrusts. All are more or less crystalline, but this condition is most apparent in the massive, gray limestone and associated beds forming the eastern portion of the mass. The massive beds in the eastern portion of the hill have probably been broken within themselves and have also moved against the rocks now forming the lower western part of the hill and all of them are probably in thrust relations to younger rocks lying beneath the plain at the west. A certain amount of flowage and crystallization serving to integrate and weld layers into massive rocks, accompanied by a certain amount

of folding and fracture, were the apparent modes of deformation of the rocks prior to a bodily thrust of all the rocks to the west, over the slates.

Thrusting may produce an apparent inversion of strata, but in such cases usually very thick and massive rocks are involved. The rocks in the eastern portion of the hill at Fonda's quarry dip easterly and pass beneath a series of beds with very similar dip, but which are unquestionably much older. The two series of rocks have the guise of conformability, but one may hardly be deceived thereby. It is hardly conceivable that the inversion has been produced by overturning of these massive formations during folding. The older rocks have their position by thrust.

It should not be understood that inversion of beds has never occurred by folding, even among somewhat massive rocks; but rather that rupture and dislocation were more characteristic modes of deformation among all the rocks, on one scale or other, in western Vermont and largely on account of the presence of very massive and exceedingly competent strata among them. Even among rocks that folded the end result was often, if not usually, fracture and faulting.

South-southwest of Fonda's quarry are two old, dismantled quarries, formerly known as Rich's Lime Works. The rocks at both these places are like the gray, marbly limestone and associated yellowish-weathering beds at Fonda's. In the fields nearby are ledges of calcareous quartzitic sandstone. The rocks at and near these old quarries form low ridges or discontinuous outcrops and suggest that similar rocks may underlie some of the surface deposits of part of the lowland roundabout. There is nothing especially striking in the structural features at these localities. The dip is at a low angle to the east. The southern quarry is practically on the St. Albans line.

The Red Sandrock series of dolomites, quartzites and slates, with associated limestones, in Swanton township. The rocks which will be described under this heading probably do not include all the rocks belonging to the Lower Cambrian in Swanton. Some other rocks that probably belong in this terrane, or to some other part of the Cambrian, will be mentioned beyond.

No outcrops of the Red Sandrock series were found in Swanton north of the Missisquoi River. The western margin of these rocks at the north begins just south of the river and about one-half mile east of the gray limestone at Swanton bridge. From this point the visible margin then runs southward for a short distance to the east of the Swanton-St. Albans road and then west of and roughly parallel with it to the St. Albans line, where it bends southwesterly in the direction of St. Albans Bay.

By comparison later with conditions farther south it will appear that the present western margin of these rocks is probably, at least to some extent, an erosion trace in the course of the re-

cession of this formation eastward and that it is essentially an escarpment softened by erosion.

In Swanton the members of this Sandrock formation are not in contact with the younger rocks that lie west of them. The nearest approach to visible contact is southeast of Fonda's quarry where the eastern outcrops of the mass at Fonda's quarry are within about 100 yards of dolomite beds of the Sandrock series. As in Highgate and other parts of Vermont the extent of present and former overlap remains uncertain because a surface section does not expose the younger rocks beneath the Sandrock, east of its present western margin (see, however, Ferrisburg township described beyond). North of Swanton Junction the margin swings west of the railroad track and the older rocks lie there on a meridian occupied farther north by outcrops of the younger gray limestone. This relation is, of course, only a suggestion of appreciable overlap; but at places farther south definite contact relations support the idea that the Cambrian beds moved over the younger rocks.

Only the chief variations among the members of the Sandrock series may be noted. The history of these rocks with respect to the conditions under which they were deposited is a chapter by itself.

At Barney's quarry a mile east of Swanton village and on the western margin of the Sandrock south of the Missisquoi River, the rock has been removed for marble. The marble is a mottled red and white siliceous dolomite of "brecciated" appearance. Similar rock appears at other places in Swanton and in the townships to the south and its various outcrops often appear to mark approximately the same horizon, although it seems possible that its peculiar features are repeated in different beds. Bowlders of this rock are common on the islands of the lake and on the mainland. So far as it may be distinguished by color markings, the mottling is a variable feature and in the same bed the mottled rock appears to pass laterally into other rock of more homogeneous color and texture. While in a great many of its outcrops this mottled rock is certainly not far above the supposed plane of shear of the series of which it is a member, the rock itself does not seem to give convincing evidence that its apparently brecciated character was acquired from crushing during thrusting. If the apparent brecciation is an effect of internal deformation it would seem that unusual primary conditions must have existed, such, perhaps, as an alternation of thin beds of sandy and magnesian deposits. It is possible to imagine that such beds under pressure could be broken and crushed with subsequent welding of the whole into the massive condition which the rock now shows. On the other hand, if these rocks were accumulated in shallow water, which seems probable, it is possible to imagine that minor disturbances during deposition might have produced the confusion and

that the compacted condition was effected by consolidation under burial, or by dynamic pressure, or both. The gray and red rocks into which the mottled variety seems to grade many times do not seem to show appreciable shearing deformation.

The rock yields few if any fossils. Obscure markings that might be interpreted in different ways are found in the more homogeneous beds above and below the mottled rocks. Probably some of these represent filled mud cracks or other purely physical features of shallow water deposits.

The generally massive, siliceous dolomites, including the mottled marble, pass eastward at the surface into rusty-weathering, sandy shales or shaly sandstones, often "flaggy." The latter outcrop frequently in the pasture along the road from Barney's quarry eastward toward Donaldson's farm. These rocks carry fragments of trilobites and in their lithological features are much like the shales at "Parker's ledge" in Georgia township.

In the woods north of the pasture road just mentioned, and perhaps one-fifth of a mile from it, is a small ledge of limestone, apparently interbedded in the Sandrock formation, from which were collected several specimens of a fossil identified as *Kutorgina labradorica,* var. *swantonensis.* The writer was guided to this locality by Mr. Donaldson and Mr. Bluett of Waterbury, Conn. This fossiliferous rock was not found elsewhere by the writer.

East of Donaldson's farm, between it and a road running north and also east of the road, are numerous ledges of rusty-weathering, sandy shales which were regarded as the eastward extension of those described above and as probably of Lower Cambrian age.

Except for the limestone member the series as just described, from sections made across it at different places, was observed to form a broad band occupying nearly the whole width between the Swanton-St. Albans road on the west and the Highgate-St. Albans road on the east, and extending practically from the northern boundary of Swanton township into St. Albans at the south. The dip is usually easterly at a low angle. About a mile east of Donaldson's and about one-fifth of a mile west of the Highgate road a westerly dip was noted.

East of Donaldson's the shales seem to be more conspicuously sheared than farther west and some of them are on meridians occupied farther south by ledges of gray dolomite. It was not clear whether shales passed laterally into dolomite; but at other places yet to be described, the field relations are not inconsistent with such a view, although probable disturbances among the rocks must always be kept in mind.

The so-called "Intraformational Conglomerate" and associated rocks along the Highgate-St. Albans road and at other outcrops in Swanton. South of Hungerford Brook in Highgate, and just north of the Swanton line, begins a series of outcrops of

PLATE XXIV

Surface view of coarse limestone conglomerate near Skeels Corner in northeastern part of Swanton township.

various rocks which from their field relations all seem clearly to belong to the same formation. The principal exposures are along or near the Highgate-St. Albans road which these rocks rather closely follow southward for a distance of about four miles. Outcrops become more intermittent towards the south. At the south in Swanton, scattered outcrops in the drift extend the geographical range of these rocks east of the Missisquoi Branch of the C. V. R. R. to the base of the quartzite hills in the southeastern part of the township, and apparently show that this formation was once more widely represented over the surface than now. However, as now preserved, these rocks form for the most part a rather narrow belt on the east of the broader band of quartzite, dolomites and shales described above.

The most conspicuous member of this series is a coarse conglomerate whose fragments vary in size from small pieces to huge slabs or blocks weighing tons. With the conglomerate and forming its paste or matrix is a finely-granular (arenaceous), calcareous sandstone, which at some places forms a stratum on which the conglomerate rests, apparently conformably. The characters of the conglomerate and its associated sandstone are well shown north of Skeels Corners, to the west of the road. At this place the sandstone, which is coarsely bedded, forms an irregular stratum beneath the conglomerate about 30 or 40 feet thick. The rock is prominently siliceous and carries many small veins of quartz which have weathered out in relief against the body of the rock. The accompanying photograph shows the surface of the conglomerate at this locality. See Plate XXIV. The larger fragments of the conglomerate are often large slabs of grayish or bluish limestone and these are mingled with many smaller pieces of all sizes.

In the conglomerate the matrix is not always distinct from the included fragments when the latter are small. The material surrounding the coarser blocks is itself a conglomerate-breccia, showing many small fragments on a broken surface.

North of Skeels Corners the conglomerate and its associated rocks continue northward as a low ridge west of the road, and by intermittent outcrops along the road, nearly to Hungerford Brook. One-fourth of a mile north of the Swanton line an exposure on the west side of the road gives unbroken thin beds of bluish limestone, perhaps 2 or 3 inches thick, dipping westerly and passing upward into broken and dislocated layers.

East of the road, north of the latitude of Skeels Corners, the surface west and east of Hungerford Brook is flat, with the hard rock mostly concealed. Along the road by Webster School are low-lying ledges of slate like that in eastern Highgate, to the east of Rock River. So far as surveyed over this flat land east of Skeels Corners, no conglomerate or limestone was observed.

South of Skeels Corners, along the road or in the fields, the members of this conglomerate-limestone formation outcrop at intervals to within a mile of the St. Albans line. To the east the hard rock that outcrops here and there through the extensive surface material is largely slate; but south of the road to Greens Corners in a pasture and on the bank of Hungerford Brook is a ledge of calcareous rock that probably is a part of the formation to which the conglomerate belongs, and a mile and a fourth southwest of Greens Corners, one-third of a mile east of the railroad track are inconspicuous ledges of bluish limestones like those seen along the Highgate-St. Albans road and farther north.

Various fossils have been reported from this conglomerate formation at its outcrops in Swanton, and those occuring in St. Albans which will be mentioned later, and these have been thought to indicate a Middle Cambrian age; but much uncertainty exists as to what forms should be referred to the matrix and what to the fragments. In Swanton the beds near Skeels Corners yielded a few fragments of linguloid brachiopod shells whose characters are too obscure for precise determination. In size and shape they resemble as closely as any illustrated forms, *Lingula riciniformis* Hall, or *Glossina trentonensis* Conrad; but it would be going altogether too far to claim that they are referable to either of these species. It was not clear whether the fossils were in the matrix or not.

Southeastern part of Swanton township. In the southeastern part of the township and in adjoining parts of Fairfield the surface rises, forming hilly land. As inspected near the track of the Missisquoi branch and along the road running parallel with it on the southeast the rocks at the base of this high land consist of quartzites and dolomites much like those found along the base of the Green Mountains farther south in Vermont and are tentatively regarded as of Lower Cambrian age. The slates which underlie the flat land west of these hills, between them and Hungerford Brook, may be and probably are of Cambrian age, but their exact horizon is not known.

St. Albans Township.

(St. Albans topographic sheet.)

Location. St. Albans township lies just south of Swanton.

The lake region. The broad area of low, flat land which forms the western portion of the township of Swanton continues with practically undiminished breadth into St. Albans. In St. Albans as in Swanton the rock of this lowland belongs chiefly to the Ordovician shale formation of the region. The shore of the lake gives an almost continuous section in these rocks which have the same general characters which have been described for them on previous pages.

Away from shore the hard rocks are mostly concealed, but outcrops are found on knolls and low ridges along the roads and in the fields. Along the road from the lake shore to St. Albans, past School No. 10 and the Tuller School, the slates were traced by scattered ledges eastward to within one-third of a mile of Stephens Brook. A half mile west of School No. 10 some rusty, sandy shales yielded large numbers of graptolites, which were identified as probably *Diplograptus foliaceous,* var.

In its southern portion the lowland forms a peninsula known as St. Albans Point, which is separated from the mainland by St. Albans Bay.

Among the shales, or slates as they might fittingly be called in most cases, which probably make up most of the lowland, there occur at several places other rocks which are very doubtfully members of the shale formation. In spite of somewhat scanty representation at the present time, these rocks may possibly have some structural significance.

In the first place these rocks may be described as appearing to have a stranded position among the shales and as foreign to them. They have not been seen elsewhere in the region in such relations nor in any other relations to the shales. In all their outcrops these rocks now form dense, very much altered quartzites, weathering white, but on fresh surfaces appearing blackened as though at one time they had been in a very hot fire. They are extremely tough and break reluctantly under the hammer. Because of the way in which they weather, their outcrops are conspicuous when close at hand, although they do not form large exposures nor high elevations. In the course of a general survey of the lowland along the roads and in adjacent fields the outcrops of these rocks were sufficiently conspicuous and different from the shales to call for a special examination. With the possibility always in mind that on the islands of the lake or over the lowland bordering its shore there might somewhere be found some remnants of overthrust rocks that once lay on the shales but which have now largely disappeared by erosion, these rocks were at first hailed as possibly affording an example of what had so persistently been sought. Since their outcrops are all low and topographically merge with the surrounding slates, it is possible that they are more extensive than is apparent and possibly there are other visible ledges which were not seen.

The possible significance of these rocks seems to lie partly in their geographical situation and relations and partly in the fact that they have not been seen at any place as forming a part of the shale formation.

The northernmost outcrops which were seen lie between the lake shore and Jewett Brook, about a mile and a half north-northwest of the Point School. At this place the rock has the greatest surface extent of any of the exposures seen. It forms three low

knolls in a north-south line and smaller patches west of them. Roundabout are ledges of other rock more like the shale-slate formation, but not always of well-defined character. Typical shale, however, outcrops to the north on a meridian slightly to the east, and also westward.

A mile south-southwest on the road running from the lake shore to St. Albans Bay and one mile northwest of the Point School are other outcrops, along and near the road. In a low ridge just east of the road the bedding is distinct and there is a small fold overturned to the west.

Other outcrops occur practically on the same meridian with the last mentioned in the southern portion of St. Albans Point. About two-thirds of a mile north of Hathaway Point, at the summer place of Mr. Morton of St. Albans, shales may be seen to form a high cliff along shore. Above the bank in the yard near the highway occurs a small exposure of dense, white-weathering quartzite which appears to be in place. At the extremity of Hathaway Point the quartzitic rock appears to lie on greatly sheared and disturbed slate and the two are much involved. The relations strongly suggest a thrust contact. Along the road from Hathaway Point to "Kamp Kill-Kare" and in the fields west of this road are other outcrops of the quartzite, which westward gives place to typical shale.

The quartzite gives little or no hint as to its age. It lies on meridians which farther south on the mainland in Georgia township, south of St. Albans, are occupied by shales and overthrust limestones and members of the Red Sandrock series. It seemed to the writer not unlikely that the small areas of quartzite just described may be residuary fragments of a formerly much more extensive mass of such rocks, or of others structurally related to them, which once lay on the slates. The imagination must be exercised in such a view, but the suggestion is not without support from other field relations in nearby areas. East of Stephens Brook, north of the village of St. Albans Bay, are physiographic outliers of altered limestones, presently to be discussed, which are now nearly a mile removed from the erosion margin of similar rocks which outcrop from beneath the massive quartzites and dolomites of the Lower Cambrian Red Sandrock series. These limestone masses are quite clearly eroded thrust-inliers in the shale formation.

Equal in interest to the evidence of remarkable thrust phenomena which the region shows are the indications of the great amount of erosion which apparently must have occurred in producing the present relations among the rocks.

Limestones east of Stephens Brook in St. Albans. Leaving the main road that connects the village of St. Albans Bay and the city of St. Albans, about two-thirds of a mile from the lake shore, is a road running northward towards the Tuller School.

Along its southern portion this road is bordered on both sides by marbly gray or dove-colored limestone, but northward this rock occurs mostly on the east side of the road where it forms the lower portion of a scarp-slope that is capped by the Red Sandrock. About a mile north of the St. Albans road, west of the one running northward, are low outcrops of bluish limestone which may be of Trenton age. The gray limestone is intermingled with some sandstone and carries yellow-weathering layers. Without much doubt these rocks are the same as those at Rich's old quarry and at Fonda's quarry farther north. With some interruptions these rocks continue northward to within about a mile of the Tuller School. The dip is prevailingly to the east.

North of the village of St. Albans Bay and three-fourths of a mile west of the road just described as running northward, are two hills composed of gray limestone which has in its striped appearance at places much resemblance to certain rocks which the writer has elsewhere identified with the Chazy. The rock is altered and massive in general appearance, with obscure dip and strike. Faint markings were noted, but no distinct fossils were found. These two hills are probably joined beneath the surface material, but taken together they are isolated from the rocks forming the scarp to the east and are probably surrounded by slates. The slates are largely concealed roundabout, but outcrop to the west of the larger western hill.

In and south of St. Albans Bay village. East of the village of St. Albans Bay the escarpment formed by the gray limestone, with its associated rocks and the Red Sandrock formation and which in general borders the lowland on the east, is broken by an embayment along which ascends the road from St. Albans Bay to the city. This embayment marks a surface interruption in the band of limestone and an eastward curve in the margin of the Red Sandrock. South of the road the margin of the Cambrian rocks swings westward and in the eastern part of the village of St. Albans Bay the Sandrock is again in proximity to the gray limestone south of the brook. To the west of the dove-gray limestone occur other limestones which are much sheared and altered. Some of it appears like the dense, black limestone found with the Trenton at Highgate Springs and possibly represents the Black River. Southwest of the Catholic church and in other outcrops nearby are ledges of bluish limestone, weathering gray, which are sheared and veined with calcite. This rock shows fragments of fossils on the weathered surface and a small bowlder gave a worn brachiopod shell like *Strophomena*. The rock is probably Trenton and resembles other rock correlated with Trenton at localities to the north.

South of the village, to the east of the shore road, is gray limestone with some chamois-colored rock, associated with dense, blackish limestone carrying demilunar traces of fossils which are

like the markings which so frequently occur in the Black River. Bluish, so-called Trenton limestone, is scantily represented. All the rocks are sheared and veined with calcite. West of the shore road the grass land is flattish, with no outcrops. The shale formation probably underlies the surface material near the lake shore.

The Red Sandrock series in St. Albans township. The Lower Cambrian quartzite-dolomite series of Swanton continues southward across the St. Albans line. Along their western margin the Cambrian rocks cap the gray limestones as described above and may be seen in actual contact at two places, at least. With the limestone the Cambrian rocks form an escarpment which faces the lowland and lake to the west. In St. Albans the Cambrian massive dolomites and quartzites are most prominently exposed along a ridge about one mile wide just east of the escarpment. A section made across the strike due west of St. Albans city showed essentially the same sequence of massive reddish, gray and mottled rocks as found in the western portion of the band of Cambrian rocks as described for Swanton. A reading on a bed of the mottled "Swanton marble" gave the strike as N. 10° E. and the dip as 8° easterly. The sequence is practically duplicated at the Georgia line with approximately the same dip and strike.

East of the ridge, along the valleys of Stephens and Rugg Brooks, respectively northwest and southwest of St. Albans city, the surface is lower and the rocks are extensively covered; but apparently Lower Cambrian rocks underlie most of the surface in the area between the western marginal scarp and the main road that runs from Georgia through St. Albans city to Highgate. In the western outskirts of the city of St. Albans, north of the road to St. Albans Bay, scattered ledges of sheared quartzite outcrop only short distances from small ledges of conglomerate and slate which will be mentioned again beyond, and well-bedded quartzite, not notably sheared, forms low but prominent ledges on and near the main road from St. Albans city to Georgia, about a mile south of the center of the city.

Aldis Hill. Aldis Hill, to the northeast of the city, is apparently composed chiefly of gray quartzite. At the northern end of the hill the beds may be plainly seen dipping at a moderate angle in a direction a little to the north of west. On the northeast slope of the hill the edges of the beds are well exposed and many of them may be seen to be only from 2 to 3 inches thick. They carry frequent thin veins of quartz and are somewhat but not severely sheared.

St. Albans Hill. This hill lies partly in St. Albans and partly in Georgia township. It is a prominent eminence lying just east of the St. Albans-Georgia road.

A private road leaves the main road about two miles south of the center of the city, and passes round the northwestern end of the hill. Along and near this road, perhaps 30 or 40 rods west of the main road, are low-lying ledges of blue limestone carrying some conglomerate. The topography suggests that there is a fault at the northern end of the hill and that this limestone is on the downthrow side. On the supposedly upthrow side is massive quartzite. This apparent displacement is seemingly traceable in a southeast direction on the east side of the hill, passing to the west of the farm house. Over the hill to the west and south the rocks are quartzite, sheared quartzite or phyllite, and dolomite, in such arrangement as to suggest that possibly that there was lateral variation in the different beds and that some of the rocks were sheared more than others; also that there may have been some faulting and offsetting so as to bring different rocks along the same line of strike. The western slopes are generally steep. On the southwestern side (in Georgia) are precipitous scarps which mark dislocations.

Southeastern part of St. Albans township and adjoining parts of Fairfield and Fairfax. East of St. Albans Hill the boundaries of the townships of St. Albans, Fairfield and Fairfax meet at a common point. East of this point, at the southwestern end of Bellevue Hill, are interbedded quartzite, dolomite and mottled rocks practically on end, dipping at a high angle to the west or east. At the base of the series is a stratum of dolomite which looks as though it had been crushed. It breaks into fragments which usually have small unaltered cores surrounded by rusty, decomposed rock. These various rocks lie about a mile east of St. Albans Hill. They are regarded as forming the eastward continuation of the rocks of the hill, or as possibly lying stratigraphically just below them; but in either case as members of the Lower Cambrian series. North of these rocks quartzite forms the western base of Bellevue Hill.

Bellevue Hill. The rocks on the northwestern slope of Bellevue Hill vary somewhat in character and are prevailingly sheared into foliated rocks. Apparently depending upon their original texture they are now sometimes phyllitic, sometimes schistose or gneissoid. In one place a conglomerate was noted, sheared into a coarse gneiss in which the squeezed pebbles could be plainly seen. Distinct small folds may be observed in some places, particularly on weathered joint planes cutting across the strike. The prevailingly easterly dip, as viewed on the surface, is then seen to be that of an induced structure. The colors are greenish, gray and sometimes purplish. The rocks are all prominently siliceous in composition and in general strongly suggest the basal portion of some overlapping formation. Well-defined bedding, repeated, small, sometimes overturned folds, variations in the purity of the material and in the texture, all seem to accord best with the idea

that these rocks are later than pre-Cambrian. They are possibly altered derivatives of older rocks, not now exposed, and have been sheared into schists and gneisses whose surface exposures are deceptive.

The topography suggests that Bellevue Hill is part of an upthrust mass of rocks. The western slope is steep and is really a softened scarp. A banking of bowlder drift and a heavy covering of trees conceals the really precipitous character which the slope now has at some places. In the recognition of the upthrust relation of this hilly land at the east one finds the clue to the clearly disturbed condition of the rocks described for the southwestern end of Bellevue Hill and for the westerly dip at Aldis Hill. The beds were folded and sometimes tilted to a high angle or overturned before rupture occurred. Over the higher portions of the hilly land the dolomites have disappeared by erosion. East of the supposed plane of thrust the rocks have usually been strongly sheared.

East of St. Albans city. East of the city a road leads eastward over the rugged, hilly land to the French School. The rocks along this road were carefully inspected. As exposed at the surface they vary from slaty phyllites through coarser, darker colored schistose or gneissoid quartzites to gray, granular quartzites in no regular order. Slaty phyllites are more abundant eastward.

The limestone conglomerate and associated rocks in St. Albans. Mention has already been made of the small outcrops at the northern end of St. Albans Hill and in the western outskirts of the city. The latter locality, commonly known as "Adam's pasture," is one that has been visited by many geologists in their studies of the stratigraphy of the region. Logan was one of the first to report upon the rocks at this place (Geology of Canada, p. 858) and described them as part of a band that was traceable for about one-fourth of a mile north of the road before it disappeared. Logan also described another band of conglomerate about one-fourth of a mile to the west at the base of a mass of whitish sandstone. Both conglomerates were described as carrying fragments of pure gray limestone. Immediately beneath the base of the western strip "occurs a band of dark gray, slightly micaceous slate, with *Obolella cingulata.*"

The writer's observations at Adam's pasture showed that what is present of this conglomerate formation is partly surrounded by not very distant outcrops of sheared quartzite, and afforded nothing definite as to the primary or secondary structural relations of the various rocks.

In the conglomerate the fragments of gray limestone are imbedded in a matrix of calcareo-siliceous material like that found in the conglomerates of Swanton and Highgate.

West of the Central Vermont R. R. track, a half mile north of the Georgia line, is another prominent exposure of the conglomerate formation, perhaps two acres in extent. With unimportant variations the rocks are like those at Skeels Corners. The conglomeratic portion shows large and small fragments of bluish or grayish limestones, with some sheared, marbly limestone, in a calcareo-siliceous matrix which weathers to a yellowish gray. In association with the conglomerate are distinctly bedded ledges of arenaceous rock much like the conglomerate matrix. At this locality none of the thinly-bedded, bluish limestone was seen, but at the northern end of the exposure is a substantial thickness of blackish slates which seem to lie beneath the conglomerate and which have some resemblance to those found in association with the blue limestone at Highgate Center. The formation including the conglomerate, of which outcrops at various places in Highgate, Swanton and St. Albans have now been described, has yielded fossils to various investigators, but its age has not been completely determined nor its relations positively elucidated from such fossils as have been found. From its apparent relations to other Cambrian rocks and from such fossils as have been discovered the formation has been called Middle Cambrian. Dr. Walcott thought that the fossils collected by himself and by G. E. Edson indicated such an age. He listed thirteen species as found in the various members of this formation, among which *Paradoxides,* which was reported from the "argillite," seemed to argue very strongly for a Middle Cambrian age for the formation.

The distribution and characters of the various rocks which seemingly are to be regarded as together making up this singular formation may be susceptible of another interpretation, in spite of the apparent nature of the fossils. There is little doubt from what observation the writer has made that the removal of the surface covering would disclose a wider extent of these various rocks than their present outcrops show.

Georgia Township.

(St. Albans and Milton topographic sheets.)

Location. This township which lies just south of St. Albans is also bordered on the west by the lake. It is bounded by Fairfax on the east and by Milton on the south.

The slates and gray limestone along and near the lake shore in Georgia. The gray limestone and associated rocks found lying to the west of the margin of the Lower Cambrian Red Sandrock series in St. Albans continue southward into Georgia, forming intermittent exposures between the lake shore and the margin of the Red Sandrock series. The limestone seldom reaches the shore, but is separated from it by the slate formation with which it is in intimate field association at several places. The outcrops

of the gray limestone and its companion rocks in Georgia may be briefly described.

East of the shore road running south from St. Albans Bay village, and a half mile south of the St. Albans line, on "Shore Acres farm," the gray limestone with interbedded, yellow-weathering layers, in some places may be seen dipping easterly at a high angle. The rock is, however, generally much sheared with partial obliteration of the bedding. The gray rock is associated at this locality with beds carrying markings that indicate a Black River age. The structural relations are obscure. Above the limestone to the east are the Lower Cambrian gray and mottled dolomites dipping easterly at a low angle.

Just west of the shore road, south of "Shore Acres farm" and between it and Mill River, are outcrops of sandstone with the beds dipping easterly at a high angle. Just west of the sandstone is bluish limestone which looks very much like the Trenton. The dip is again easterly at a high angle and the sandstone and limestone appear as though interbedded.

South of these outcrops is Mill River. In the bed and along the sides of the river, above and below the bridge, is exposed a gray sometimes obscurely striped limestone. Above the bridge the dip is not clear, but below it the bedding may be seen to dip easterly at a high angle, measured at one place as 53°.

About 200 paces west of the bridge the gray rock is succeeded westward by apparently conformable sandstone and shaly limestone which continue west for about 60 paces and are then followed by shaly limestones and shales. In the river section no beds were noted which had any resemblance to Black River rocks.

Gray limestone outcrops in the angle of the roads just south of the Everett School and one-fourth of a mile farther south on the east and west sides of the shore road. At Lime Rock Point the gray limestone reaches the water's edge, while south of the point the bank of the lake is formed of slate like that of the St. Albans lowland and the islands lying to the west, but indescribably crushed and jammed so that its included firmer bands of rusty, siliceous rock are squeezed and faulted out almost to obliteration.

East of the road on the farm of Mr. Wilcox the gray limestone is clearly much disturbed and greatly sheared. Just south of Wilcox's house black slate outcrops in the road and a fourth of a mile farther south the shale-slate formation may again be seen forming the shore cliff where the road closely hugs the shore just north of Melville Landing.

The slate forms the shore from the small point south of Melville Landing to the Milton line. Throughout this distance the margin of the Red Sandrock series is one-fifth a mile or less from the lake shore. The Cambrian rocks form the summit of a

sharp slope against which is usually piled a large amount of drift. Through this covering the hard rocks outcrop at intervals.

South of Melville Landing near the top of the slope lie great blocks spread about "like ruins." Some of these are quartzite and others are composed of bluish-gray and chamois-colored limestone with a "brecciated" texture not unlike that of the mottled Swanton marble. Southward along the intermediate levels of the slope at several places the soil indicates that the slate formation is close to the surface and at one place about two miles south of Melville Landing the black slate was found outcropping well up the slope. A half mile farther south the gray limestone with abundant calcite veins appears from beneath the Cambrian dolomites and forms a conspicuous hill at the western base of which the black slate outcrops.

About two and a half miles north of Camp Rich the shore road turns abruptly eastward away from the bank of the lake which it closely follows to this turn. Slate outcrops where the road turns again southward. East and south of this slate outcrop is gray, often sparry limestone of uncertain correlation. One-half mile farther south, east of the road, sparry limestone has about the same dip as the Cambrian dolomite that clearly lies above and on it. West of the road is other limestone which continues nearly to the slate along shore.

As indicated above, the lake is formed of the shale-slate from the St. Albans to the Milton line, except at the Lime Rock Point. It thus appears that along the Georgia shore the same general relations prevail among the slates, gray limestones and Cambrian dolomites as in Highgate, Swanton and St. Albans. In Georgia it seems probable that at some places the Cambrian rocks rest directly upon the slates, as will be conclusively shown to be the case farther south, and as may be the case at certain places north of Georgia; but in Georgia and places north of it the surface covering leaves some doubt.

There can be no doubt, however, that the relations among the rocks along the lake shore in Georgia clearly mark thrusting and dislocations and show that older rocks have moved over younger ones. There was probably involved at least one great low-angle thrust by which the Cambrian rocks were moved to the west. Whether the gray limestone and its companion rocks were secondarily involved in the thrust that drove the Cambrian westward and were carried along with the latter, or whether they are rocks that were independently driven on the slates on which they now rest and were overridden by a later major thrust of the Cambrian it is not possible to tell. Either history seems possible.

The escarpment formed by the margin of the Lower Cambrian Red Sandrock and the various limestones that lie beneath it in southwestern Georgia is over a mile to the west of the meridian on which are located the fragmentary outcrops of quartzite which

were described for St. Albans Point. It seems likely that the present margin of overthrust rocks north of Georgia is an erosion trace of a mass of older rocks that once had an extension to the west of the present western limit of these rocks and that the fragments of quartzite now isolated within the slate formation on the St. Albans lowland may be really remnants of resistant members of such a mass. This seems probable, even though it must be recognized that the thrust of the older rocks on the slates may not have carried them so far west in higher latitudes as it did in Georgia and farther south, for which idea one finds some support in the present northeasterly trend of the margin of these rocks in northwestern Vermont and in their extension northward into Canada.

The Lower Cambrian Red Sandrock series of quartzites and dolomites and associated shales in Georgia. The massive gray, red, and mottled members of the Red Sandrock series near the lake in Georgia are indistinguishable from the similar rocks in the townships to the north. They do not appear to have suffered any notable internal deformation and plainly dip at a low angle to the east. Away from the lake the hard rock is more extensively covered by surface material and emerges as knolls, hills and ridges of varying dimensions. Around Georgia Plains and northward along the headwaters of Mill River the underlying rock had clearly been somewhat dissected before the surface covering was spread over the region.

About a mile and a half north of Georgia Plains and about the same distance east of the lake is a hill known to residents as "Parker's Ledge." This locality has long been celebrated for the Lower Cambrian fossils which have at various times been found there. The farm of which the hill forms a part is now owned by Mr. Montcalm. The prevailing rocks at the "Ledge" are dense black or sandy, often micaceous, rusty-weathering shales, which after diligent search may now afford fragments of *Olenellus, Olenoides, Microdiscus* and other fossils. These shales have great similarity to the rocks of Swanton which lie to the east of the gray and mottled dolomites of that town and like the shales of Swanton have some dolomite associated with them. Some of the dolomites at the "Ledge" are of gray color and others are rusty-weathering, siliceous rocks. The rocks at the "Ledge" have for the most part a flattish position or dip to the east at a low angle.

A half mile south of the "Ledge" on the farm of Mr. Sartwell quartzitic shales are interbedded with dolomite, but westward on the Densmore farm the shaly members occur in greater force and have much similiarity to those at the "Ledge." These shales carry "fucoidal" markings, which are probably trails, but did not yield other fossils. They give place westward at the surface to the gray and mottled members of the Red Sandrock series.

The gray and mottled rocks near the lake in Georgia township are thus seen to pass eastward at the surface into somewhat different rocks with which they may be conformable. The general surface sequence and the dips of the various rocks suggest a continuous stratigraphical series, but it is not certain that the apparent conformity is everywhere real and that dislocations do not intervene among these various rocks that seem with more or less definiteness to be of Lower Cambrian age.

In the northern part of the township the dolomites are succeeded eastward at the surface along the road crossing Mill River, which passes School No. 7, by sheared quartzite, which also outcrops frequently along the main highway from Georgia Center to St. Albans, to the west of St. Albans Hill. Similar rock outcrops around Georgia Center; but west and southwest of Georgia Center the quartzite is intermingled with areas of limestone conglomerate presently to be described.

The road running directly east from Georgia Center ascends a slope over sheared quartzite. There is then an interval along the road of a little less than a mile with no outcrops. Near the junction of this road with one running south past School No. 11 are numerous ledges of massive gray and mottled dolomite clearly dipping westerly. A reading gave the dip as 37° and the strike as N. 10° E. These rocks may be followed northward and southward along their strike. Southward, about a mile and a half from the junction of the roads just mentioned, massive dolomite was noted dipping westerly, and northward, a mile north of Oakland, are similar rocks also dipping westerly. The latter outcrops are two-thirds of a mile southwest of Bellevue Hill, described above. Dolomite outcrops along the road on the lower western slope of Cushman Hill, but is succeeded farther up the slope by quartzite.

Taking into account the low easterly dip of the members of the Red Sandrock series at their western margin and the suggestion of their possible extension in that attitude eastward beneath the surface the westerly dips of the rocks just described might seem to show that the beds in question form a broad, shallow syncline over most of Georgia township west of the C. V. R. R. track. It is possible that they do and that the higher dips at the east represent a pushing up of the eastern limb, with crushing at some places (Bellevue Hill). The massive beds ruptured instead of folding, the rocks east of the railroad track now occupying the upthrow side of a reverse fault-thrust. But as mentioned above it is not certain that dislocations do not intervene between the western margin and the railroad track, so that it cannot be positively stated that Georgia shales are conformably above the dolomite series near the lake, although they seem to be.

The limestone conglomerate formation in Georgia. In Georgia the most conspicuous outcrops of the conglomerate, or of

limestone that is apparently to be correlated with it, occur west of Georgia Center and east and southeast of Georgia Plains. On account of surface covering the outcrops are intermittent and of variable extent in present surface exposure. West of Georgia Center the conglomerate has all the essential features of the rock in St. Albans and Swanton. It carries abundant limestone fragments of different sizes in a matrix of strongly siliceous material which has enough calcareous matter to effervesce freely with acid.

Dr. Walcott in his early account of the Georgia section described the conglomerate as apparently forming a great lenticular mass of limestone, with intercalated beds of argillaceous shales, and more rarely with arenaceous layers imbedded in the argillaceous shales. The fauna was described as Cambrian in character, and, in the absence of *Olenellus* and other typical Lower (then called Middle) Cambrian fossils, as approaching the Upper Cambrian.[1] In his diagram of the Georgia section, Walcott shows the conglomerate formation as an interbedded member of the Georgia series. In referring to the vertical distribution of the fossils (loc. cit., p. 20) he remarks that one species of the typical Georgia fauna. *Ptychoparia adamsi,* "is represented in the great 'lentile' of the Georgia section," but he drew the provisional upper line of the Georgia Formation at the base of the lentile, as it is at this horizon that there occurs a decided change in fauna and that the deposit changes markedly from that below.

Several years later,[2] after the recognition of the Lower Cambrian age of the Georgia shales (the fauna of these shales having been regarded by Walcott in his earlier studies [1886] as Middle Cambrian) Dr. Walcott reproduced his early diagram of the Georgia section, showing the conglomerate as an interbedded member of the Georgia series and stated that it contains a fauna that may prove to be of Middle, or possibly Upper Cambrian age.

In commenting on the Georgia section as late as 1911,[3] Ulrich said: "The base of the section is here unknown. As worked out by Walcott, the lowest exposed formation is a limestone 1,000 feet thick. This is succeeded by 200 feet of 'Georgia shale,' and over this comes 3,500 feet of shale and thin limestone. A quartzite 50 feet thick follows and is in turn overlain by 1,700 feet of limestone and shale, and this by 3,500 feet of shale. I have seen only the upper part of this section, namely, the heavy bed of shale last mentioned, which, together with all the underlying beds has been referred to the Lower Cambrian by Walcott. Regarding the upper shale I am strongly inclined to view it as of Canadian age rather than Cambrian. There is some question in my mind, also, concerning the age of the limestone supposed to belong to the 1,700-foot bed. It contains small bivalved phyllopods (*e. g.*,

[1] Bull. U. S. G. S. No. 30, 1886, p. 17.
[2] Tenth Annual Rept., Director U. S. G. S., 1890, pp. 553-554.
[3] Revision of the Paleozoic Systems, Bull. G. S. A. No. 22, 1911, p. 617.

Indiana dermatoides (Walcott), *I. pyriformis* Matth., *I. secunda* M., *Bradoria scrutata,* M.) which are characteristic of Lower Acadian zones in New Brunswick and Newfoundland. As it is not yet decided whether the Protolenus zone is late Lower Cambrian or early Middle Cambrian, the exact age of the Vermont bed mentioned also remains uncertain." He then comments on the complicated structure of Vermont rocks and of those of the Taconic area in particular.

In the writer's studies of the structural relations of these rocks it was not possible to show that the conglomerate is interbedded in the shale series, or that it could not be interpreted as resting unconformably upon eroded rocks. The field relations leave much uncertainty as to the stratigraphic relations of the conglomerate to the rocks with which it is associated in Georgia. If the conglomerate lies in a broad, open syncline of Lower Cambrian rocks it might be interpreted *structurally* as belonging to any formation later than Lower Cambrian, and if its fossils are truly Middle or still later Cambrian they might be regarded as forming a primary fauna, or as secondarily included in a later terrane by erosion of Middle or later Cambrian rocks.

Fairfax Township.

(St. Albans and Milton topographic sheets.)

This township bounds Georgia on the east.

Near the summit of Cushman Hill, about two-thirds of a mile north of Silver Lake and just east of the Georgia line, the present surface apparently marks erosion into the lower portions of an overlapping formation. At numerous outcrops the rock, which may be a rusty, impure quartzite or a greenish-gray, schistose quartzite, carries scattered large grains or rounded pebbles of grayish-white quartz. In dimensions these pebbles range from the size of a marble to that of an egg. The pebbles are apparently not sheared, but the rock in which they are included is sometimes schistose.

The significance of this imperfectly developed conglomerate and the obvious impurity of its matrix in places seems to be that the rocks of this higher land are not a great way above or distant from the old sea-floor on which the series of which they are a part was deposited; but no unconformable contacts nor any recognizable older rocks were seen. The conglomerate is not purely local, for similar rock was observed three miles farther east in Fairfax, near Buck Hollow, and five miles to the north in St. Albans, and also at the northern end of Bellevue Hill. The conglomerate is, however, everywhere local in the sense that it grades laterally into impure quartzite, or derivatives of impure sands. It is, therefore, intraformational in this sense; it is basal only in the same general sense. It indicates particular local conditions of

deposition and perhaps minor oscillations. It can hardly be interpreted as forming residuary parts of a formation that rested unconformably upon the other rocks with which it is now associated.

At the northern end of Georgia Mountain, in the southeastern part of the township, along the hill road running east, south of the Lamoille River, are outcrops of gneissic-looking rocks with foliations dipping easterly at a high angle. On their weathered surfaces, and on vertical joint or fracture planes across the strike, these rocks give somewhat the appearance of squeezed conglomerates with the foliations bending gently around squeezed fragments; but the latter, on close inspection, have little appearance of pebbles distinct from a matrix, and when the rock is broken it looks much like somewhat impure quartzite. On the whole the rock most suggests a sheared and welded quartzite, whose resistance to deformation resulted first in shearing and brecciation. The rock was then healed and compacted into a gneiss. The rocks are succeeded eastward by outcrops of granular quartzite.

CHITTENDEN COUNTY.

Milton Township.

(Milton topographic sheet.)

Location. Milton, another lake shore township, lies just south of Georgia. The southern boundary of Georgia forms the northern boundary of Milton, throughout its extent. Westford lies to the east and Colchester borders it on the south.

The lake border in Milton township. The escarpment, capped by the massive beds of gray, red and mottled dolomites, which closely follows the lake shore in Georgia and part of St. Albans continues southward into Milton. In Milton, as in Georgia, younger gray limestones and slate or outcrops of slate alone intervene between the margin of the Red Sandrock series and the lake shore.

North of Camp Rich, gray limestone occurs between outcrops of slate in the shore road and the margin of the Red Sandrock series. South of the camp, towards Camp Watson, the margin of the Cambrian rocks more closely approaches the shore and outcrops of gray limestone are fewer. The shore road from Camp Rich to Camp Watson is nearly all the way on the slates which continue south to Eagle Mt. Camp at the mouth of Stone Bridge Brook.

South of the mouth of Stone Bridge Brook, Eagle Mt. rises to a height of 500 feet. It is composed of the massive dolomites of the Red Sandrock series and has a steep scarp on the west which was estimated in some places to be 200 or more feet high. The Cambrian rocks continue southward with somewhat diminished but still conspicuous scarp to the vicinity of Camp Martin

(generally known as Camp Milton). Between Eagle Mt. Camp and Camp Milton the margin of the Cambrian rocks is perhaps 300 feet from the lake and the slope between is steeper than is usual farther north, apparently largely on account of large talus blocks which have fallen from the scarp and which are now partly covered with drift. Between Eagle Mt. Camp and Camp Milton the slate formation shows continuous outcrop along shore and throughout this distance gray limestone was not noted between the shore and the scarp, except just north of Camp Milton.

East of Camp Milton is an erosion gap in the margin of the Red Sandrock series. Trout Brook flows along the southern margin of this gap to enter the lake.

The indication is strong that between Eagle Mt. Camp and Camp Milton the Red Sandrock series frequently, if not usually, rests on the slates. Just north of the mouth of Stone Bridge Brook the slates form isolated shore cliffs 50 feet high without any traces of overthrust rock resting on them. Just south of the mouth of the brook the massive dolomite of the Red Sandrock formation reaches close to the water edge with only a high water or storm beach of slate shingle between it and the shore, no outcrops of slate or other rock being visible. The topography and geology suggest a fault along the gap mentioned above, the rocks at the north occupying the upthrow side. The dolomite continues south along the eastern edge of the swampy delta of the Lamoille River to the delta portion of the Sandbar Bridge road, showing as a low cliff of varying height, to the east of which the surface ascends over the eroded edges of other members of the Red Sandrock series. South of the delta road the erosion margin of the overthrust dolomite series is less easily followed to the bank of the Lamoille River.

Between Trout Brook and the Lamoille the dolomite probably rests on the slates just as it does at Red Rock Point near Malletts Bay in Colchester.

The steep western face of Eagle Mt. gives suggestion of what the faded scarp all along the margin of the Cambrian Red Sandrock formation may once have been. It seems quite likely that the erosion modification of these resistant rocks along their present trace was subsequent to the formation of the lowland in the weaker shales and limestones in what is now the lake region. It is, however, not apparent from the present relations of these various rocks how far the Red Sandrock may have extended to the west of its present erosion trace. It is interesting to note that in some places the Cambrian rocks rest by thrust on limestone and at other places on shales or slates that are younger than the limestone. Such relations should have something to say about the mode of deformation by which the present relations could have been produced.

Just east of the road that runs from Camp Milton eastward, about half a mile from the lake shore, a ledge of brick-red quartzite-dolomite displays a texture which differs strikingly from that which the mottled "Swanton marble" member of the Red Sandrock series shows. The rock as a whole forms a massive bed in which may be clearly seen many angular fragments of different sizes, including blocks of rectangular shape as seen in section which bear strong resemblance to similarly shaped fragments seen in the limestone conglomerate formation. Moreover, the angular pieces are mingled with other larger, irregularly shaped chunks, giving an assemblage like that in much of the limestone conglomerate. The fragments are, however, of much the same color as the rest of the rock and apparently are composed of a material similar to the matrix in which they lie. From the conditions it is not possible to tell whether the fragmented rock is an intraformational conglomerate or a peculiar form of brecciation. A similar fragmental rock of gray dolomite occurs west of Checkerberry village and will be mentioned beyond.

The west-central portion of Milton township. East of the escarpment that borders the lake the surface over the west-central portion of Milton is largely formed of sand plains through which the hard rock emerges as dwarf exposures which are often fragmentary and unsatisfactory for study. Arrowhead Mt., Cobble Hill and the gorge of the Lamoille River give more extensive outcrops.

From the escarpment near the lake the massive beds of the Red Sandrock series extend eastward with low easterly dip, forming in the western part of the township a fairly well defined band of varying breadth from the Georgia line to the Lamoille River. East of this band the members of the series lose distinctness as one passes into the areas of more scattered outcrops of the west-central part. Between the western band just mentioned and another strip to the east that includes Arrowhead Mt., the village of Milton and Cobble Hill, the exposures are prevailingly gray dolomitic rock, rather sparingly associated, so far as the rocks are visible, with a more quartzitic rock, without any very clear structural relations between the two. Some of the outcrops may now be mentioned.

North of the Lamoille River, to the east and west of Streeter Brook, are numerous outcrops of gray dolomite which give way at places along the strike to quartzite. The relations suggest either that dolomite grades laterally into quartzite, or that different but conformable beds are exposed in different outcrops. Either interpretation seems possible, if, as seems likely, the rocks are to be correlated in a general way with the members of the series along the lake. By such correlation is not meant precise stratigraphic equivalence, but membership in a common formation which gives good indications that horizontal variation in its different beds

was a common if not a usual condition and that dolomites and more siliceous beds succeeded one another in a more or less regular fashion within the formation.

From Milton village to the lake the Lamoille, in sinking its channel since glacial times, has cut through hard rock at many places, producing a considerable fall near Milton village and minor ones farther west. The rocks which the river has thus cut through show some interesting differences.

At West Milton the river cuts massive gray dolomite, which outcrops in both banks and in midstream. A mile above this village the rock is more notably siliceous. These rocks appear to be the southward continuation of those lying west of Streeter Brook, to the north. Farther up stream, from the point where Streeter Brook enters the Lamoille to the abutments of the old stage road bridge near the Milton Town Farm, the rock along the stream is a slate, with easterly dipping cleavage. Where worn by the water the rocks often show pseudolaminations probably corresponding with the cleavage. At places above the high-water mark the rock is often a dense slate. The river cascades approximately along the strike over these slates below the old bridge site, forming what are frequently called by the residents the "minor falls." The slates continue upstream towards Milton village and seem to pass beneath other rocks forming the upper falls at the mill of the International Paper Company. The slates near the upper falls have been jammed and sheared with obliteration of bedding and folded structure. Folding was seen at only one place. Induration is the rule. The rock which apparently overlies the slate at the upper falls is a somewhat indeterminate mass of gray dolomite and quartzite. At some places the rock shows a texture precisely like the "Swanton marble," but without the conspicuous variegated coloration. For the most part the rocks resemble the members of the Cambrian series near the lake. They are generally massive in present appearance, although there are observable planes of separation which may represent bedding or jointing. At the falls the massive rocks are cut by a dike 4 to 8 inches wide running across the strike. A dike of similar rock, with apophyses, cuts the slates just west of the mouth of Streeter Brook. The rock that makes the falls continues as a scarp into the woods north of the falls. The general relations suggest that the dolomites have been pushed over the slates that lie under and west of them.

Upstream above the falls, well shown both above and below the bridge and sparingly along the streets in the village near the bridge, is indurated quartzite.

Southwest and west of Milton village, south of the Lamoille, is a broad, flat, sand plain with no outcrops except at its western edge, west of Checkerberry village. A half mile northwest of this hamlet, low ledges of dolomite show the peculiar conglom-

erate or "brecciated" texture noted in previous pages as occurring in a reddish bed of the Sandrock series near the lake, in the limestone conglomerate and in the gorge at Highgate Falls.

North of the Colchester line and east of the road from Checkerberry village to School No. 9, is gray dolomite dipping easterly. This rock continues easterly across the road that runs west of Cobble Hill, but on the western slope of the hill the dolomite is marked by frequent inclusions of chert and lies at the base of a modified but still notable scarp in the schistose quartzite that makes up the principal portion of Cobble Hill and that outcrops north of it and along the road that skirts it on the east.

North of Milton village the Lamoille is deflected to a southward course by the mass of Arrowhead Mt. which rises to a height of 947 feet and forms a conspicuous feature of the township. The eastern slope of this mass shows gray dolomite and quartzite, often sheared, but at places showing clearly defined westerly dip. The westerly dip is conspicuous at the southern end of the mountain proper. West of Arrow Mt., along the road at the western base, are black, fine-grained, siliceous slates.

South of Arrowhead Mt., and about a mile north of Milton village, quartzite forms bold, massive ledges west of the Georgia road. The quartzite beds have been sheared so as to give a more massive appearance than they really possess, a feature common among these rocks in which shearing has welded not always especially heavy beds into very massive looking rocks. The quartzite just mentioned joins southward with that above the falls in the village.

A broad surface section from the river in Milton village eastward along the road to School No. 6, shows that the quartzite at the river is succeeded eastward by gray dolomite and quartzite which form a low ridge just east of the railroad track. The rocks are sheared but at places show a westerly dip. As one ascends the hilly land east of the village, dolomite and quartzite roughly alternate across the strike on the lower portion of the slope; but higher up the slope dolomite is absent and much of the rock, while apparently originally a quartzite, shows a gneissoid structure like that which has been described for the northern end of Georgia Mt. The rock sometimes shows the bedding across which the gneissoid structure has been developed. The gneissoid rock is succeeded eastward by ledges of not severely sheared quartzite, which may be seen in the vicinity of School No. 6. At some places the quartzite, including that which has been sheared into a gneiss, is disposed in gentle folds.

The gneissoid rock might be regarded by some observers as something different from the quartzite with which it is associated, but there are no contacts nor other field relations suggesting that the rocks are members of different formations. The

possibility that older rocks might have been thrust into the quartzite formation must be recognized; but when the gneissoid structure appears in a bedded quartzite and when the quartzitic character of other gneissoid rock is so obvious and no valid distinctions may be made among numerous exposures over large open fields, the membership of these different rocks in a common formation seems the ready and reasonable interpretation and the differences seem to be explainable as due to various degrees of shearing and primary differences in composition.

The quartzite and its gneissoid associate continue south from the road to School No. 6 towards Colchester, along the higher portions of the western slope of the hilly land; but on the lower portions of the slope the rock is quartzite.

A section was made along the road that runs from School No. 10 to Bowmans Corner in Westford. The quartzite at the western base of the hilly land continues to the bend in the road two miles west of Bowmans Corner. The rock is sheared, with strong cleavage dipping easterly. South of the road, at the bend mentioned, white quartzite is associated with brick- or cherry-red quartzite in such relations as to indicate that the two rocks are lateral color variants of each other. Eastward along and south of the road to Bowmans Corner are frequent ledges of gray siliceous dolomite which is more or less intermingled over large areas with quartzite and this quartzite-dolomite series extends eastward nearly to the corner.

From the descriptions which have been given it will be seen that much the same kinds of rocks and structures occur in Milton as in Georgia. Near the lake the members of the Red Sandrock series dip easterly at a low angle. Farther east are dolomites and quartzites in scattered outcrops which apparently belong to the same formation. Along meridians passing through and east of Milton similar rocks show westerly dip at many places or are apparently broken and thrust on rocks lying west of them. Most of the rocks so far mentioned probably belong to the same general formation in which there are differences among the beds due to primary horizontal and vertical variations and to secondary shearing effects. It appears that the underlying hard rock away from the lake shore in Milton is probably essentially a Lower Cambrian surface as is the case in Georgia. There are, however, among these rocks some others which are not easily correlated with them, such as the slates found along the course of the Lamoille River, west of Milton.

Certain rocks in Westford township, adjoining Milton on the east. At Bowmans Corner and along the road towards Essex Junction is greenish slate or phyllite which over long distances is more or less interchangeable with quartzite. The greenish slate shows coppery-colored phyllitic and schistose variants and all have

a good deal of similarity to similarly associated rocks at some places in the Taconic hills many miles to the south.

A section along the road from Milton village by the Hardscrabble School to Westford gives quartzite at the western base of the hilly land, then farther up the hill the gneissoid quartzite, then a wide band of greenish slate, which is the northern extension of that near Bowmans Corner and then around Westford village quartzitic schist which was followed over the high land southwest of Westford village along the road to Essex Center by the Beecher School. At the east the quartzitic schist frequently carries segregated quartz and as a mass strongly resembles similar rocks found in the Sudbury Hills.

The limestone conglomerate formation in Milton. The extensive sand plains in Milton probably conceal some of this formation. South of the hamlet of West Georgia, but south of the Georgia line, are a few scattered ledges of rock, some of which bear such close resemblance to thinly-bedded limestone members of the conglomerate formation in Highgate and St. Albans that there is little doubt as to their correlation with each other. The exposures are few and were the only ones seen in Milton except some fragmentary rocks found seven miles to the southeast, near School No. 3, about a mile north of the Colchester line. At the latter place, east of Malletts Creek and the railroad track, are a few ledges of limestone, some of which resemble those found to the north. No conglomerate was seen.

Colchester Township.

(Plattsburg, Milton and Burlington topographic sheets.)

Location. This township is bounded on the north by Milton, on the east by Essex, and on the south by Burlington and South Burlington.

The rocks along and near the lake shore in Colchester. In Colchester township along what is now the border of the lake, pre-glacial erosive processes had breached the massive dolomites of the Red Sandrock series, producing a considerable basin which is now flooded by the lake waters and is known as Malletts Bay.

North of Malletts Bay, between it and the Lamoille River, various knolls and ridges give extensive outcrops of the members of the Sandrock series which have been traced from St. Albans along the margin of the lake. The erosion margin of these rocks may be followed south from the Lamoille, east of Camp Winnisquam, to Red Rock Point, where the formation dips into the lake. North of Red Rock Point the slates show in cliffs and low outcrops along shore and at Clay Point form a pinnacle capped by Champlain clays. About 200 rods north of Red Rock Point, massive dolomite may be seen in contact with the slates.

Around the bays and headlands of the serrated north shore of the Bay and nearly to its eastern limit are perpendicular or rugged cliffs of gray or mottled dolomite much like that at Red Rock Point. Similar rock outcrops along the road from Camp Winnisquam to the Colchester-Grand Isle road. The dip is easterly.

In a minor indentation at the northeastern portion of the bay is a beach of sand at the edge of a swamp that marks the southern end of a small valley. In the western wall of this valley the rocks are massive but apparently in somewhat thinner beds than those farther west and display the reddish and pinkish colors characteristic of the Sandrock series farther north. On the east side of the valley the rocks are prevailingly quartzitic and in thinner beds, which weather white, gray and rusty brown. Fossils were sought in the rusty layers, but without success. In some of these rocks around Malletts Bay the late Mr. Griffin of the Survey had found *Olenellus* and other fossils, but unfortunately, his localities have not all been described in print. A low scarp which bounds these quartzite beds on the west continues southward along the eastern edge of the swampy land and along the eastern shore of the lake north of the mouth of Allens Brook. Along this scarp may be seen lateral variations in the colors and thicknesses of the beds. The quartzite continues south of Allens Brook to the sandy beach that borders the bay on the southeast and south.

West of the sandy beach on the southern side of the bay a peninsula known as Coates Island juts into the bay. West of the "Island" and separated from it by a small bay is a peninsula known as Malletts Head which projects northward to within about one-half mile of Red Rock Point and somewhat to the west of it. The head forms a remnant of an old erosion margin of the Red Sandrock which was breached to form the bay. On the western shore of the Head the Ordovician slates underlie the dolomite which forms the surface rock of most of the peninsula. The relations at the head are entirely similar to those north of Red Rock Point, and there is little doubt that slate lies beneath the portion of the lake forming the inlet to the bay; but whether slate underlies any considerable part of the bay as the hard rock surface may only be conjectured.

The Red Sandrock lying on the slate on the western side of Malletts Head is two-thirds of a mile west of that at Red Rock Point, and unless there is a fault between, this fact points to a former more westerly extension of the dolomites farther north, confirming in a measure the suspicion that the margin of the Sandrock at least for some of its course north of Malletts Bay is a recession border.

The rocks of Colchester peninsula, west of the meridian of Malletts Head, to the north of the Winooski River, were not

inspected by the writer. The map of the Vermont Report shows most of the peninsula as underlain by "Utica" or "Hudson River" slates and, therefore, as not having any of the Sandrock on it much to the west of the meridian of Malletts Head.

The Sandrock of Malletts Head and Coates Island is separated from other exposures of this formation lying south of them by a sand plain, the extension of which eastward and southward forms a wide, sandy, partly swampy tract stretching from the sandy beach that makes the southern border of Malletts Bay to the Winooski River. Along the eastern border of this tract, around the Colchester Town Farm, are outcrops of the Sandrock formation which are the southward continuation of the beds forming the east shore of Malletts Bay.

The altogether remarkable vertical variations shown by the quartzite-dolomite series known in this region collectively as the Red Sandrock has been described by Professor Perkins from his own detailed studies and those of his assistant, the late Dan Griffin.[1] Differences in composition, thickness and color appear in irregular but frequent succession between and within the different beds along different sections through the formation. Lateral variations with respect to composition and color may also be seen when the beds of this formation are followed along their strike. Impure sands, fairly pure sands and sandy muds seem to have been contemporaneous with each other and often at places not very far removed from one another during the deposition of these rocks. Many of the beds give clear evidence of shallow water accumulations, probably on a slowly-subsiding sea-bottom and one which underwent intermittent oscillation of level. Reddish shades of color, probably due to oxidation under atmospheric exposure, frequent cross bedding, and many markings that seemingly could have been produced only in relatively shallow waters, or on exposed flats, all bear testimony to the nature of the conditions under which these rocks were laid down.

There seems to be good reason for thinking that large areas of this Red Sandrock formation once formed a surface of erosion and unconformity on which other strata were deposited; but it is extremely doubtful if any considerable portion of such surface is anywhere now preserved over the region where this formation makes the outcropping rock. With the facts in mind that the color variations which are assumed to be due to some degree of oxidation of the material of the rock are repeated throughout considerable vertical distances in this Red Sandrock series and that lateral variations occur within continuous beds; that large exposures of this formation at the present surface hold to a fairly uniformly gray color which is presumably a primary feature; and that thrusting has doubtless tended at least to produce an imbricating rather than a conformable series in the forma-

[1] Sixth Rept. of the State Geol., pp. 227 et seq.

tion, as a whole it is difficult to attribute the red color, where this may be shown to be an ancient character of the rock, as due to atmospheric changes following the elevation and erosion of the rocks subsequent to their deposition as a series. The possible explanation of the "brecciation" shown by the mottled members of this formation as a primary feature has been discussed above. All the noteworthy features of the Red Sandrock series are well shown in the vicinity of Malletts Bay.

The age of this primarily conformable series has definitely been made out by the discovery of *Olenellus* and *Ptychoparia adamsi* in some of the beds near the bay.[1]

East of the lake in Colchester. East of the lake much of present surface is formed of sand. Gray dolomite or rusty, flaggy quartzite outcrop here and there along meridians in the central part of the township and dolomite and schistose quartzite which appear to be interbedded give numerous outcrops along the east road from Colchester village to Milton. The schistose quartzite grades laterally into more massive quartzite. The prevailing dip is easterly; a westerly dip was not noted.

Two miles east of the Town Farm, ledges of gray siliceous dolomite carry bunches of segregated quartz and some lace-like tracings of silica on the weathered surface. These features give the rock an appearance somewhat like that shown by some of the rocks in Highgate just south of the Canada line, which probably belong to a Beekmantown horizon; but such features are clearly altogether too indefinite for purposes of correlation and while the markings referred to were not noted in the rocks near the lake, they may well be present there and in any event might readily have been produced by agents of hydrothermal metamorphism in such siliceous rocks. There seems no good reason for regarding these particular rocks as other than Lower Cambrian.

A mile east of the Town Farm a quarry opened for road metal shows beds of gray dolomite dipping very gently to the east. Uniformity of color gives at first sight a somewhat massive appearance, but close inspection shows beds of moderate but variable thickness. Sections of the bedding planes, as seen in the face of the quarry which was opened along the strike, usually show as ammonoid-suture-like lines, often of brownish (limonitic) color. The bedding surface shows that these lines are traces of partings between irregular pittings or hollows on the surface of one bed into which project small cones from the under surface of the overlying bed. Separation of the layers may sometimes be complete along the pitted surface of the beds, but again will be accompanied by horizontal fracture across the little cones when there will appear small gray patches surrounded by irregular brown lines. The irregular surfaces seemed to indicate shallow rather than deep water deposits. These rocks are a half mile

[1] Sixth Report, p. 229.

or so east of the Red Sandrock ledges near the Town Farm. They are probably part of the same formation.

In the western part of Colchester village are low ledges of gray dolomite. These rocks are on the meridian of those in the quarry mentioned above. On the same meridian farther north, south and east of Munson Flat, are excellent exposures of rusty, flaggy quartzite which carries obscure fossil markings, but which yielded nothing definite.

The rocks of Colchester, so far as seen by the writer, seem to belong to a common formation and to be of Lower Cambrian age. No rocks were noted in this township which could be correlated with the limestone conglomerate, or with other rocks which have been noted in northern townships that seemingly were not so easily placed in the Lower Cambrian formation; but the apparent or actual absence of such rocks may be a circumstance due to covering, or erosion, or to the particular nature of the secondary structures of the rocks of this area.

Essex Township.

(Milton and Burlington topographic sheets.)

Location. This township adjoins Colchester on the east. It is bounded on the north by Westford, on the east by Jericho, and on the south by Williston and part of South Burlington.

General description. The rocks of Essex are the eastward continuation of those of Colchester and the southward continuation of those in Milton and Westford.

In western Essex, north of Essex Junction and east of the road from the Junction to Colchester village, quartzite and dolomite, apparently interbedded, form the western slope of hilly land over which ascends the road from School No. 2 to Butlers Corners. The rocks dip easterly and are entirely similar to the rocks of eastern Colchester. The quartzite is often somewhat mashed and veined with quartz. These rocks are succeeded along the road to Butlers Corners by greenish slate or phyllite. Slate was traced to a half mile east of Essex Center.

In the eastern part of the township the rock is prevailingly a quartzitic schist, carrying segregated quartz, and is the continuation of similar rock south of Westford village. On account of shearing, the primary structural features of the rocks in the eastern part of the township are obscure.

Black quartzitic schist outcrops in Essex Junction.

At the bridge across the Winooski, beneath the dam above and below the bridge, is gray siliceous limestone or dolomite, often much crushed and strongly crystalline. It holds to a rather uniform color and character throughout the considerable mass exposed. At one place at its western edge, below the bridge, the jammed limestone can be seen resting on crumpled blackish slate

on which it has apparently been thrust. The ages of these rocks are problematical. The limestone has been tentatively called Beekmantown. It is part of the band called the Eolian Limestone in the Vermont Report. The descriptions of the members of this band have not differentiated among the different kinds of rock found in it. As will appear in later discussions there is much variation and probably rocks of very different ages are associated. The structural relations are everywhere very obscure.

Burlington Township.

(Plattsburg, Milton and Burlington topographic sheets.)

Location. Burlington lies just south of Colchester. The lake forms its western boundary and it is bordered on the east and south by South Burlington.

The lake shore and vicinity. The northwestern part of the township forms a part of what may be called the Colchester-Burlington peninsula. In this part the land is low like that of the adjoining part of Colchester, from which it is separated by the Winooski River. East of this lowland is higher land marking the southward extension of the Red Sandrock of Colchester. Northwest of Burlington, at a promontory variously known as Sharp Shins, Split Rock Point, Lone Rock Point, or simply as Rock Point, the Sandrock reaches the shore. At this place it is often a yellowish magnesian sandstone, as weathered. On the south side of the point it rises abruptly from the water, but northward on the west it rests by thrust on crumpled Ordovician slates. This locality gives the finest thrust contact of the Red Sandrock on the slates anywhere to be seen and has been frequently fully described. The slickensided under surface of the Cambrian rock is most impressive.

From Rock Point southward, west and southwest of Burlington, a low sandy beach extends for a distance of over three miles, nearly to the blunt promontory marked at its southwestern extremity by Redrock Point. This point should not be confused with the one bearing the name Red Rock Point at Malletts Bay.

From outcrops near Lakeside Park to Queen City Park, the rock along the water edge is the variegated Sandrock, but in general is distinguished by red or reddish colors. Northward the ledges are low and permit one to walk close to the water, but near and at Redrock Point are bold, precipitous cliffs. Ripple marks and mud crack patterns are frequent in these rocks as at other places near Burlington. The beds dip to the east. These red rocks may be traced at the surface eastward through Redrocks Park. No massive gray dolomite was noted in association with them.

The rocks at Redrock Point undoubtedly extend eastward beneath the surface deposits to join with those at Willard's Ledge,

now commonly known as Phelps' quarry, a locality in the southern outskirts of Burlington, to the east of the main road from Burlington to Shelburne. In the quarry one has fine opportunity to observe the variations in thickness and shades of color from bed to bed and to see various forms of markings due to their shallow water origin. The series is cut by dikes of igneous rock.

About a mile to the east-northeast of Phelps' quarry, along the road from Shelburne Falls to Burlington, are low ledges of gray sandy dolomite, dipping gently to the east, which presumably lie stratigraphically above the beds of the quarry. This sandy dolomite is on the meridian of gray dolomite lying on the red beds at Winooski lower falls, which will presently be mentioned.

Within the city of Burlington, outcrops of the Sandrock are few, but drilled wells in the western part of the city are described as penetrating this formation and there is no doubt that the city is underlain by it.

Gorge of the Winooski. The Winooski, like the Lamoille, has cut post-glacial gorges along its course and the rocks so exposed, with some that occur in Winooski village and to the east of it, may be conveniently described at this point.

At the falls in Winooski village are red beds much like those on the east shore of Malletts Bay and south of Burlington. Above these red beds in midstream and in the south wall of the gorge, below the bridge, is more or less massive-looking but obviously bedded, grayish dolomite. The reddish beds below the gray rock are prevailingly thin, of various shades of red color, often brick-red, and carry here and there ripple marks, mud cracks and some cross-bedding. The beds thin out and thicken laterally and have all the marks of shallow water deposits.

Gray dolomite outcrops in Winooski village in the railroad cuts, on the line of strike of the similar rock in the river bank below the bridge. On the south side of the river, in Burlington, east of the Greenmount Cemetery and west of Grove Street, are typical variegated beds of this formation dipping gently easterly.

It will thus be seen that along and near the lake in Burlington the Red Sandrock shows the same general characters and dip that it has farther north along the lake shore.

About a mile east of Winooski village the river has cut a winding gorge. At the hydroelectric power plant the wall of the gorge is made of gray siliceous rock which eastward appears to pass beneath other rock that is more calcareous and which in fact at the lime-kilns is a marbly limestone which is quarried for lime. No sharp line of separation was found between the two kinds of rock. In the old and new quarries at the lime-kilns the rock is strongly crystalline, remarkably uniform in appearance and without distinct bedding. A similar lack of bedding appears in the massive, weathered rock as it outcrops near the quarry in the wall of the gorge just below the bridge. West of the new

quarry, south of the river, surface exposures in the fields show bluish-gray, marbly limestone puddled with yellowish-gray rock. The latter as eroded most often appears as patches and streaks on the marbly rock. The white-weathering, marbly rock occurs north of the river and the railroad track, to the west of the highway bridge, and passes westward at the surface into gray, siliceous rock.

No fossils were obtained from any of these rocks and their structural relations are problems not yet solved. In notable particulars the limestone in the quarries and adjacent fields has very strong resemblance to the similar rocks east of Highgate Springs and south of Swanton village.

Professor Perkins has told the writer that fossils were found by Griffin in Colchester, north of the lime-kilns, which seem to be of Beekmantown age (*Rhaphistoma canadense* Bill. and *Cryptozoon wingi* Seely).

East of the lime-kilns the Winooski winds through a sand plain to the falls at the bridge south of Essex Junction.

South Burlington.

(Burlington topographic sheet.)

Location. This township bounds Burlington on the east and south. For a mile and a half south of Redrock Point the shore of Shelburne Bay forms its western boundary. Williston lies to the east and Shelburne to the south.

General description. The red beds of the Sandrock formation pass beneath the surface covering near Queen City Park, and the shore southward to the southern boundary of the township shows no outcrops. East of the shore, sand is plentiful; the eastward extension of the red beds in South Burlington may only be conjectured. Sand plains extend to the northwestern part of the township, to the bank of the Winooski River.

About two and a half miles southeast of Burlington a road from the Williston turnpike crosses Potash Brook. At this place is white, marbly rock like that at the lime-kilns two miles to the north.

Southeast of these outcrops and again southward along the road from Williston turnpike to Hinesburg and between the road and Muddy Brook are numerous ledges of limestone. Some of these are composed of thinly-bedded, bluish rock, of which the bedded characters are somewhat better shown in outcrops a little to the east in Williston, and other ledges are more massive looking rocks of somewhat striped appearance as though thin layers had been welded by shearing into more compact and thicker beds. This massive, striped rock is particularly well shown at the schoolhouse about two and a half miles south of the Williston turnpike. The rocks were searched for fossils without success. They

lie on meridians a little east of those occupied by the marbly limestone and its associates at the lime-kilns east of Winooski. There is some resemblance between certain members of the limestones near the Winooski gorge and those in the southeastern part of South Burlington. The rocks at these two places are much more readily correlated with each other than either are with the gray, sandy dolomite (siliceous limestone) found in association with the red beds of the Sandrock formation at the west and that with which they or similar rocks are rather intimately intermingled a little farther south in St. George and Hinesburg.

In Hinesburg and Charlotte and townships south of them, marbly limestone is often in intimate field association with rocks of very different character and which may be correlated without much hesitation with the Lower Cambrian; but these latter rocks are quite similar in all essential features to rocks which more distantly surround the white, marbly or bluish limestones of South Burlington and Williston. In other words, there is a rather close correspondence between various rocks in South Burlington and Williston and others in the townships to the south of them; but the field intimacy among these rocks that are apparently of very different age is much more pronounced in some areas than in others.

Williston Township.

(Burlington topographic sheet.)

Location. Williston lies east of South Burlington. It is bounded on the north by Essex, on the east by Jericho and Richmond and on the south by St. George and a part of Hinesburg.

General description. In Williston, along and west of the road running south from Essex Junction to Hinesburg, about one and one-fourth miles from the outcrops in the river at the bridge south of Essex Junction, Allen Brook cuts through gray, siliceous limestone or dolomite much like that at the bridge.

The Hinesburg road crosses the Williston turnpike. One-third of a mile south of the turnpike, east of the road to Hinesburg, black, gray-weathering slate, with easterly dipping cleavage, is associated with mashed limestone or dolomite, bluish-gray on fresh surfaces, but weathering gray, which is very close to the slate. Contact is concealed. The limestone showed no discernible dip. The relations are very similar to those below the bridge south of Essex Junction, described above.

About a mile east of these outcrops, just south of the Williston turnpike, conspicuous knolls give a surface succession from west to east of siliceous dolomite, fissile, blackish and lighter colored phyllites, and quartzite. Gray dolomite outcrops a mile to the northeast, north of Allen Brook; but eastward the prevailing rock is quartzitic schist, often carrying segregated quartz.

South of Williston turnpike, east of the road running from Essex Junction to Hinesburg, except for the outcrops mentioned above, the prevailing rock is the quartzitic schist, which forms rolling, hilly land extending eastward into Richmond and southward into St. George and Hinesburg. This schist gives place at the surface westward, north of Brownell Mt. and Sucker Brook, to bluish limestone with which the schist is intermingled at places in no regular way. The arrangement gives the impression that the limestone lies on the schist. Westward toward Muddy Brook the limestone thickens and becomes more massive looking, as described above for the eastern part of South Burlington, and outcrops of schist are lacking.

At the foot of the steep western slope of Brownell Mt., near the road skirting the mountain on the west, is crushed bluish-black slate with cleavage dipping easterly and at some places clearly brecciated. The schist making up the mass of Brownell Mt. has apparently ridden by thrust over the slate. Westward the slate is succeeded by striped, bluish limestone like that described above.

Although no conglomerate was noted in the limestones south of the Winooski there is much resemblance between the striped, bluish members of them and similar rocks found farther north in the conglomerate formation. There is, moreover, a close correspondence in the associations with other rocks and in structural relations. At the north the rocks as has been shown are often no more conglomeratic than are the limestones of South Burlington and Williston.

Shelburne and St. George Townships.

(Willsboro and Burlington topographic sheets.)

Location. Shelburne lies south of South Burlington and borders the lake. The northeastern part of the township adjoins the southwestern part of Williston. St. George on the east is like a small strip cut off from the eastern end of Shelburne. On the south are Charlotte and Hinesburg. A long tongue of land belonging to Shelburne extends northward into the lake and separates the main body of Lake Champlain from Shelburne Bay.

General description. Most of the peninsula just mentioned is formed of the shale formation which extends from Shelburne Point southward on both shores, on the east nearly to the southern limit of the bay and on the west to join the shale of the mainland along which it continues with some interruptions along shore to the southern boundary of the township. Outcrops are frequent on the peninsula between its shores, but southward away from the lake the shales are mostly covered and are succeeded eastward by the red and gray rocks of the Sandrock series.

On Shelburne peninsula the shales, or slates, carry the firmer, rusty-weathering bands so characteristic of this formation all along the lake shore north of Burlington and in general lithological features are like the members of the formation on the islands and the mainland in the northern part of the lake region.

It seems probable that the lake bottom in Burlington and Shelburne Bays is underlain by the slates, in which these indentations of the shore have been excavated, probably in some cases after a covering of overthrust rock belonging to older limestones or to the Sandrock series had been eroded. The general field relations all about suggest such a history and further give some support to the view that in Shelburne and other places where these friable mud rocks have been preserved they owe their preservation to a covering of more resistant rock that was removed at a relatively recent date. Juniper and White Islands are insular outcrops of the shale to the west of the peninsula.

The slates on Shelburne peninsula are cut by numerous dikes which have been described by Kemp.[1]

The Sandrock forms headlands on the southwest shore of Shelburne Bay and gives numerous outcrops between the bay and the village of Shelburne. The red beds are conspicuous along the Shelburne-Burlington road just north of the LaPlatte River and these and other members outcrop west and southwest of Shelburne village. The dip is at a low angle to the east.

East of Shelburne Falls, to Shelburne Pond, the rocks are gray, siliceous dolomites not distinguishable from the similar beds around Shelburne village. The rocks just east of Shelburne Falls are on the meridian of those in the eastern part of Burlington.

East of Shelburne Pond, between it and the main road from Burlington to Hinesburg, the prevailing rocks are marbly or bluish limestones, forming the southward continuation of those in the southwestern part of Williston and the southeastern part of South Burlington. Near the Hinesburg road these limestones give place to gray, siliceous dolomite which continues over the western boundary of St. George township. East of the dolomite in St. George the hilly land is made of quartzitic schist which joins that of Williston and Hinesburg.

A generalized surface section from west to east across the areas south of the Winooski River, which have so far been described, gives the Ordovician shale formation at the west, then the Red Sandrock series of red and gray quartzites and dolomites, then a very different kind of rock that is a metamorphosed limestone, and finally quartzitic schist with some gray dolomite on the same meridians with the schist both of which belong to the same general formation. The types of rock and the sequence are the same as in the townships north of the Winooski. The varia-

[1] Bull. U. S. G. S., No. 107, 1893.

tions are perhaps less significant than the similarities, from a structural viewpoint.

Charlotte Township.

(Willsboro and Burlington topographic sheets.)

Location. Charlotte lies south of Shelburne and borders the lake. It is bordered by Monkton on the east and by Monkton and Ferrisburg on the south.

The rocks along and near the lake in Charlotte. From the Shelburne line to the latitude of Wing's Point the lowland along the lake is made of clay, with few outcrops of the shales along shore.

On the road running from Charlotte village westward to the lake shore and McNeil's ferry, about a mile east of the shore, Black River limestone, carrying the markings so familiar in this formation in the lake region, dips westerly at a low angle and is underlain apparently by Upper Chazy with similar westerly dip. Nearer the lake are Trenton beds, also dipping westerly at a low angle or lying nearly flat. At the water edge just south of the ferry the dark blue Trenton rocks are full of well-preserved and characteristic basal Trenton fossils. After a surface interruption along the shore of the bay south of the ferry the Trenton beds appear on the north shore of Cedar Beach promontory and continue around its border to McNeil Bay. At Cedar Beach promontory the dip changes to southeast or east. These Trenton rocks are nowhere severely altered. They are in fact like the Trenton rocks of Grand Isle and Isle La Motte. In respect to certain features of alteration they differ from the Chazy just as do the beds on the islands mentioned.

On the west shore of a small promontory that juts into McNeil Bay are beds that were correlated with part of Brainerd and Seely's Beekmantown. A third of a mile farther east are magnesian rocks of doubtful correlation, but probably also Beekmantown. These are followed eastward by ledges of Chazy limestone, dipping easterly, and carrying *Girvanella ocellata* Seely. There seems to be exposed a small patch of Black River to the east of these Chazy rocks.

The road on Thompson's Point crosses diagonally a series of beds that appear to belong to the Beekmantown by comparison with the Shoreham section. The beds dip at a low angle to the southeast.

On the southeast shore of the bay, south of Thompson's Point near the Ferrisburg line, are Chazy beds dipping to the southeast.

The various massive beds described as probably Beekmantown or recognizable as Chazy, are not folded, but as shown by changes in strike from place to place and by visible geographic offsets are twisted, and broken across the strike and probably

along it. On the whole the rocks do not show pronounced indications of internal deformation. There is nothing to show their relations to the slates that probably lie north of them under the clay-covered lowland. The writer's field map indicates that shale lies on a meridian to the east of these massive, basal Ordovician rocks; outcrops were noted a mile north of Charlotte station and also a few rods west of Ferrisburg station in the adjoining town of Ferrisburg. These various rocks in southwestern Charlotte belong to the lake region proper, as defined in the early part of this paper. The probable relations among them may be judged from those shown by other rocks in townships farther south.

East of the Rutland railroad track in Charlotte. South of Charlotte station is a considerable mass of igneous rock forming Barber Hill. The rock has been described as Bostonite (a soda-rich, acid, dike-forming rock). Similar rock forms dikes on Shelburne Point and in North Ferrisburg village.

East of the railroad track in Charlotte township by far the largest part of the visible rock emerging through the drift belongs to the Sandrock series. East of Charlotte village the reddish members of this formation form Pease Mt. Along the road that runs southward, east of Pease Mt., similar rocks dip easterly and join with the red beds of Mt. Philo. The rocks of these two mountains are on meridians which are occupied farther north by the Sandrock formation in Shelburne, but which to the south in Ferrisburg are occupied by comparatively unaltered shales, thinly-bedded, dark blue, basal Trenton limestone and Chazy rocks which belong to the lake series and are in fact the eastward extension of the rocks along the lake in Ferrisburg.

East of Pease Mt., around East Charlotte, exposed at several places along or near the road running in a north-south direction through the village, are outcrops of beds of siliceous dolomite, dipping easterly at a low angle. On this road, about a mile and a fourth north of the village, is marbly limestone; but a mile farther north the gray dolomite outcrops again and continues towards Shelburne Falls.

Around Prindle Corners, two miles southeast of East Charlotte, interbedded quartzite and dolomite show a series much like that found around Middlebury and Brandon to the south. The rocks in southeastern Charlotte and adjacent portions of Hinesburg indeed mark a transition in the Lower Cambrian formation from the generally more massive, interbedded, siliceous and magnesian rocks of the Sandrock series in the northern townships and the recognizably thinner beds of what has been called by the writer in earlier papers the "interbedded series" of the Lower Cambrian in the Vermont valley.

As a consequence of their more thinly-bedded character, the rocks around Prindle Corners and neighboring parts of Hines-

burg are frequently jammed into close folds so that the beds stand at high angle of dip or even on end.

Northeast of Prindle Corners along the road and in the fields the Cambrian quartzites and dolomites are intermingled with marbly rock, but the field relations as usual give no definite clues as to the structural relations.

Hinesburg Township.

(Burlington topographic sheet.)

Location. Hinesburg lies east of Charlotte.

General description. In the southwestern part of Hinesburg are interbedded quartzites and dolomites which join with those around Prindle Corners in southeastern Charlotte. The beds are usually sharply folded with high easterly or westerly dips, but along the meridians of such closely folded rocks, at other places the folding was not always so severe. The interbedded rocks east of Prindle Corners continue southward into Monkton and northward in western Hinesburg, but in northwestern Hinesburg are considerable exposures of marbly limestone, which, so far as the hard rock is now visible, seem more or less definitely to be surrounded by gray, siliceous dolomites.

West of Mechanicsville, along and west and east of the Hinesburg road, the gray dolomite is abundant and forms a conspicuous ledge known as High Rock on the east side of the road. Massive, gray dolomite occurs between Mechanicsville and Hinesburg and in numerous massive and prominent ledges southeast of Hinesburg on the east side of the road to Starksboro, continuing southward nearly to the township boundary. The extension of the dolomite east of the main road is irregular, being most marked in hollows around Mechanicsville and Hinesburg. East of the main road the land is mostly hilly and made of quartzitic schist. Dolomite and schist at different places occupy the same meridians and the field relations show that the two rocks are members of a common formation and that the preservation of the dolomite along the western margin of the hilly land is due to certain favorable structural relations resulting from the deformation of the rocks.

It will thus be seen that from the lake shore eastward through Charlotte and Hinesburg a broad surface section gives near the lake the shales and comparatively unaltered limestones of clearly recognizable Lower and Middle Ordovician ages, then an abrupt transition to the Red Sandrock of Pease Mt. and Mt. Philo which are succeeded eastward by gray dolomites and interbedded dolomites and quartzites more or less intimately intermingled in their present surface outcrops with marbly limestone, and finally the massive, gray dolomite and quartzitic schist of the hilly land at the east. A field inspection is essential in order to appreciate

fully the similarity which such a section has in rock types, sequence and general field relations with the sections in northern townships which have been described, and its correspondence in all essential particulars with areas farther south. These resemblances are clearly due to what may be called strict homology, to borrow a biological term, in the secondary structural features and in certain primary relations which obtained among the various rocks, although all of the rocks may not be of precisely similar age.

The Lower Cambrian formation is seen to show from west to east and from north to south many variations of thickness, color and sequence in the vertical arrangement of its beds, corresponding with lateral variations in the original character of the material and variations in the conditions under which the material was deposited from time to time. North of Weybridge the more purely terrigenous rocks of this formation are found in the hilly land by which the Champlain lowland is joined to the mountains farther east, but such rocks also form the present surface rock over portions of the eastern edge of the lowland. South of Weybridge the terrigenous rocks are extensively preserved in the Taconic hills.

ADDISON COUNTY.

Ferrisburg and Vergennes.

(Willsboro, Burlington, Port Henry and Middlebury topographic sheets.)

Location. The township of Ferrisburg and the city of Vergennes are conveniently discussed together. Ferrisburg is on the lake shore south of Charlotte. On the east it adjoins Monkton and part of New Haven and on the south is bounded by part of New Haven, Waltham, Vergennes and Panton. Vergennes forms an area two miles square which is bounded by Ferrisburg on the north, by Ferrisburg and Waltham on the east, by Waltham and Panton on the south and by Panton and Ferrisburg on the west.

General description. Ferrisburg is a large township and includes a variety of rocks, all of which may be correlated with others which have been described in previous pages, but some of which show field relations of great interest in relation to the general structure of the region. Description will begin with the western and central portions.

Around Camp Meeting Point, north of the mouth of Lewis Creek, fossiliferous Chazy limestone forms a low, anticlinal fold. Between the point and the railroad track are low outcrops of shales which are undoubtedly younger than the rock at the point.

Near Bluff Point, west of the Little Otter, much of the rock is apparently of Chazy age. Specimens of *Maclurea magna*

were found near the road from Kingsland Bay to Ferrisburg, at the bend in the road about two-thirds of a mile east of the bay. The beds dip gently eastward. East of this place outcrops are largely concealed along the sluggish creek.

Limestone outcrops at intervals along the road that runs south from Kingsland Bay. Just south of the junction of this road with the one that runs from it to Fort Cassin Point are extensive outcrops of probably Chazy limestone, dipping easterly; but about one-fourth of a mile from the main road along the one to Fort Cassin Point, graptolitic shales were noted. At Fort Cassin Point, which is probably really an island surrounded partly by water and partly by the delta and levee deposits of Otter Creek, are limestones which were assigned by Brainerd and Seely to division D of their Beekmantown formation. Bedding is distinct and the layers have a flattish position. The rocks are more or less indurated but fossiliferous. Although great numbers of different species have been found at this locality, particularly in the weathered rock, fossils are now found only after diligent search in the firm, unweathered rock. Seely states that the Fort Cassin rocks were assigned to division D by Brainerd after careful stratigraphic study of the region. The fauna of these rocks is in need of further careful study in order to be sure of its exact horizon. The apparent separation at the surface by shales of the rocks at Fort Cassin from the Chazy beds mentioned as occurring along the road to Kingsland Bay suggests that the succession east from the lake is probably not a conformable one, but rather that breaks, probably of the nature of thrusts, intervene.

East of the probable Chazy rocks on the Kingsland Bay road the surface is all clay. The hard rock underlying the clay is probably all shale.

West of Otter Creek and south of Kellogg Bay, are outcrops of fossiliferous Chazy which lie on a meridian slightly to the west of the Fort Cassin beds a mile to the north. With some interruptions the Chazy beds, dipping everywhere to the east, form the shore and slopes adjacent to it from Summer Point at Kellogg Bay southward past Basin Harbor to Button Bay. At many places, notably at Basin Harbor and between it and Button Bay, the beds afforded excellent specimens of *M. magna* and *Girvanella*. Near Kellogg Bay perhaps not all the rock belongs to the Middle Chazy; at Summer Point the beds may belong to a lower division of this formation or to Upper Beekmantown.

Eastward again between the outcrops along shore and Otter and Dead Creeks, presumably the underlying rock is shale, which is found in scanty, low outcrops along the road from Basin Harbor to Panton; but sand plains along the Otter and elsewhere clay conceal the rock to within a mile and a half of the city of Vergennes.

The Chazy rocks that form the point which projects towards Button Island, near Button Bay, pass eastward beneath clay which forms most of the shore of Button Bay. Along the shore south of the bay the shales outcrop for a distance of about two-thirds of a mile north of the Panton line. Fossils collected from these shales and those along the Panton shore southward by Gould and Ruedemann were assigned by Ruedemann to three different horizons in the Canajoharie shale of Trenton age.

About one and a half miles west of Vergennes, north of the Otter and between it and the road running from Vergennes to Fort Cassin and Kingsland Bay is a hill of badly crushed, magnesian limestone, without fossils or distinct structure. A mile to the east, north of the road, and just west of the playgrounds of the Industrial School are excellent outcrops of massive Chazy beds, dipping gently to the east and carrying numerous coils and opercula of *M. magna* and abundant specimens of *Girvanella*. East of the playgrounds and north of the city, similar beds with similar fossils dip to the west at an angle of 34° and strike N. 40° E. East of these outcrops, west of the railroad track, is a road running north to Ferrisburg. East of this road, respectively a half mile and a mile north of the westerly-dipping Chazy beds just mentioned, are other Chazy beds dipping easterly. The structure thus shown by the Chazy northwest and north of Vergennes shows the formation to be disposed in gentle anticlinal and synclinal swells. More altered rocks of probably Chazy age at Marsh Hill and south of it, to the northeast of the city, form a gentle, anticlinal fold.

At Vergennes falls the river tumbles over massive, grayish, magnesian limestone which apparently dips easterly. Close inspection shows it to be crushed and brecciated, but now healed into a compact rock. Seely called this rock Beekmantown.

Below the falls, near the boat landing on the Industrial School grounds, shales carrying numerous graptolites, identified as *G. quadrimucronatus*, outcrop in the low bank of the stream. Between the falls and the westerly-dipping Chazy beds north of the city, described above, shales or argillaceous limestones, usually much sheared and slickensided and filled with small veins of calcite, outcrop along the road, apparently exposed from beneath a mass of overthrust Chazy.

About two miles northeast of Vergennes, west and east of the main road from Vergennes to Ferrisburg, east of the railroad track, are Trenton beds somewhat sheared, but carrying hosts of recognizable basal, Trenton fossils, including *Calymene senaria*. *Cryptolithus tesselatus*, linguloid forms and bryozoa. These rocks are particularly well exposed on the land of Carl Fields. The Trenton rocks form a ridge between the main road and the one running from it to the west of Shellhouse Mt.

A half mile northeast of this ridge of fossiliferous Trenton, southeast and east of Ferrisburg village, are outcrops of Chazy limestone which are on meridians on which lie the rocks at Marsh Hill and south of it, as mentioned above. Rocks of apparently Chazy age continue northward, east and west of the road on the west of Shellhouse Mt. North of the mountain the road ascends over blue, Trenton rocks, which as outcropping in the road gave Trenton fossils, including *C. tesselatus.* Towards Mt. Fuller these Trenton beds are associated with more massive, dense limestones, weathering a light gray, now shattered and filled with calcite veins and which strongly suggest the Black River, and are in fact much like recognizable Black River rocks found farther south in Waltham and Addison townships. Sheared limestone, probably of Trenton age, continues northward along the cross road west of Mt. Fuller nearly to the North Ferrisburg-Monkton road. At one place along this cross road, sheared limestone is in contact with quartzite and probably overlain by it. One-third of a mile to the east is a scarp in the quartzite that makes Mt. Fuller.

At North Ferrisburg village, Lewis Creek has cut down into crumpled, black shales or shaly limestones which are exposed in the bed and banks of the stream at many points in the village and west of it towards the lake. Northward on the meridians of these shales in the creek is the Red Sandrock of Mt. Philo. These shales have been called "Utica"; they are without much doubt younger than the rocks that form the hilly land south and southeast of them.

The rocks that apparently belong to the Chazy formation and form the surface just west of Shellhouse Mt. give place in the steep western face of the mountain to white quartzite which is notably jammed. The quartzite extends eastward, giving place near the township boundary to interbedded dolomites and quartzites, all, including the quartzite at Shellhouse Mt., dipping easterly at a low angle. The interbedded rocks form a band along the eastern edge of the township and southward join with similar rocks in New Haven. South of Shellhouse Mt. the Cambrian rocks pass under drift and between the band of interbedded rocks at the east and the limestone of Marsh Hill and neighboring exposures is an area of low, flat land, with no outcrops; but directly north of the mountain, as has been shown, are limestones and shales of the lake series which occupy the meridians of the quartzite of the mountain and the interbedded, Lower Cambrian rocks that lie east of it.

The Trenton and Black River limestones southeast of North Ferrisburg village and the shales in Lewis Creek are visibly sheared or shattered rocks and somewhat metamorphosed, but are readily recognized and traced as the eastward extension of the rocks near the lake. They are notably less crystalline and

marbly than the calcareous rocks found among the Lower Cambrian rocks on meridians farther east. The occurrence of the Lower Cambrian rocks north and south of North Ferrisburg village on the same meridians with the little altered lake rocks near the village and the extension of the present margin of the former at Pease Mt. in Charlotte to a meridian over a mile west of that passing through North Ferrisburg village, point to thrusts by which the older rocks rode over the younger. It is also probable that the massive limestones of the lake series rode over younger shales, either by independent thrusts or during the translation of the Cambrian beds.

The field relations near Vergennes certainly suggest that the older limestones of the lake series have ridden over the younger limestones and shales. The latter are sometimes sheared and crushed. At Vergennes falls the dolomite is brecciated; but the Chazy beds northwest, north and northeast of the city are not folded much. They are most sheared and altered in their eastern outcrops; but even then may sometimes lie flat, as may be seen near the cemetery east of Ferrisburg village.

The conditions around Vergennes seem to show what was argued to be the probable structure on the islands in the northern part of the lake. They also give support to the idea that a great, low-angle thrust carried the Lower Cambrian beds over the rocks of the lake region and that to some extent, at least, the present western margin of the former is an erosion trace of an overthrust mass of which some portions have disappeared.

Monkton Township.

(Burlington and Middlebury topographic sheets.)

Location. Monkton lies east of Ferrisburg and is bounded by Charlotte and Hinesburg on the north, by Starksboro on the east, and by Bristol and part of New Haven on the south.

General description. This township includes a prominent physiographic outlier of the Green Mountain plateau, generally known as "Monkton ridge," which enters Monkton from Bristol at the south and extends through the central portion nearly across the township. To the east of Monkton ridge, and separated from it by a valley of irregular surface, another prominent ridge, known as Hogback Mt., and which is also an outlier of the main range, enters from Bristol and extends northward just west of the eastern boundary to within about a mile of the northern township line.

These prominent physiographic features are fundamentally of structural origin. They are interpreted as primarily thrusted masses which were later modified by normal faulting. The depression which now separates Monkton ridge from Hogback and that which separates the latter from the main range is in each case

a more or less perfectly developed *graben* and on a small scale illustrates the structural character of the famous Vermont valley, which beginning farther south near Brandon extends to Pownal between the Green Mountain plateau and the Taconic range. The structural and physiographic features in the eastern part of Monkton and adjoining parts of Starksboro have their counterparts at other places along the western edge of the Green Mountain plateau.

Into the northwestern part of Monkton township the reddish beds of the Sandrock series extend from the southeastern part of Charlotte and give conspicuous outcrops on the low hillsides at many places. East of the road from Monkton to East Charlotte, northeast of Mt. Fuller, the red beds are interbedded with some dolomite and the dip is gently to the west.

At Mt. Fuller and southward along the road to Barnumtown, beds of cherry-red quartzite form conspicuous outcrops and dip to the east at a low angle. A low scarp bounds Mt. Fuller on the west. It is interpreted, as in some degree a recession scarp, for one-third of a mile to the west of it a fragmentary patch of quartzite rests against sheared, probably Trenton limestone, as noted above.

South of Mt. Fuller the surface falls off to slightly lower levels and apparently the purple quartzites pass under somewhat higher members of the Sandrock series; but whether this is actually the case or whether the interbedded quartzites and dolomites forming the surface rocks southward represent lateral variations of the beds at the north may not be easily decided.

Near Barnumtown the interbedded series appears in force and at places shows most severe effects of compression, being not only jammed into close folds, but twisted along the strike and otherwise deformed. The interbedded rocks continue south from Barnumtown over Cronkhite Hill and along the road to New Haven Junction. At some places the members of this series lie in flat attitude, but within short distances such beds pass apparently both along and across the strike into others that are highly inclined and greatly jammed. These features have much resemblance to others which have been described for quite similar rocks around Brandon (see first paper) and have their counterparts in other localities yet to be described.

In the northern part of the township, along the road from North Ferrisburg to the village of Monkton Ridge, are low-lying outcrops of closely-folded, interbedded quartzites and dolomites which are the southward extension of those in southwestern Hinesburg and near Prindle Corners in Charlotte.

Two miles farther south, just west of Monkton village (Monkton Borough), similar rocks with cherry-red quartzite members form the hill known as Mt. Florence and show numerous outcrops in the fields directly north of the hills. In the hill red

quartzites apparently dip gently to the west, while directly east of the hill the members of the interbedded series are jammed into close folds and are sheared and crushed.

From Monkton Borough, over the ridge to East Monkton, the rock is mainly quartzite or quartzitic schist, apparently for the most part dipping easterly. Just north of East Monkton village rather thinly-bedded, quartzite beds stand on end or by apparent overturn now dip easterly at a high angle. These rocks are sheared and slickensided and give every indication of having been jammed against the beds that lie west of them.

Distinct scarps, irregularly disposed and overlapping more or less along the general strike of the rocks, are distinctly visible features along the eastern face of the ridge north of East Monkton village. These scarps probably mark planes of faulting by which the rocks that lie in the valley of Pond Brook have been left at lower levels. Quartzite forms the eastern slopes and scarps of Monkton ridge from East Monkton to Monkton Ridge village. South of the latter village, east of Monkton Pond, the gray and white quartzite is distinctly sheared so that the dip is obscure.

For a mile and a half east of Monkton Ridge village the rocks are distinctly bedded, gray dolomites, lying flat or dipping westerly, but just west of the northern end of Hogback Mt. the dip of the dolomite changes to easterly and this rock gives place eastward to quartzitic schist, or sheared quartzite, with some members of pure white, granular quartzite. Eastward towards the road that runs from Hinesburg to Starksboro the quartzite gives place to gray, siliceous dolomite, usually of massive appearance, but carrying some thin beds.

In Monkton township, just as in Hinesburg at the north, as one goes east from the western margin of the Cambrian rocks towards the hilly land, the interbedded rocks are seen to give place at the surface to dolomite or quartzite, apparently according to the manner in which displacements have altered the primary relations among the rocks. These relations are quite like those to be noted farther south in Bristol and Middlebury, and those which the writer has described for the Brandon region.

The southern portion of Monkton ridge, south and southeast of East Monkton village, is largely composed of sheared quartzite; but, as will be mentioned again later, in the northwestern part of Bristol the quartzite apparently passes beneath massive, gray, siliceous dolomite which lies to the east of interbedded dolomites and quartzites in the northeastern part of New Haven township.

The outcropping rock along the road that runs through the valley of Pond Brook is quartzite; but probably this quartzite was once overlain by dolomite like that which occurs at the northern end of the valley, to the east of Monkton Ridge village, as noted

above, and presumably the softer rock has been largely eroded over what is now the floor of the valley.

The western face of Hogback Mt. is steep and marked by prominent scarps.

No marbly limestone was noted among the Cambrian rocks just described for Monkton. Its absence seems to be correlated with the relatively higher topographic levels of the members of the Lower Cambrian series in this township. The marble appears to the south and southwest in New Haven.

Starksboro Township.

(Burlington and Middlebury topographic sheets.)

Location. Starksboro lies east of Monkton and the northeastern part of Bristol.

General description. Lewis Creek has its source in the hills of Starksboro. The stream from the junction of its headwater tributaries flows north across the township through a valley that separates Hogback Mt. from the main range. The floor of the valley is dotted with hills. As noted above, it is a structural basin secondarily modified by the erosion of much of the relatively soft rock. The hills over its floor are formed of either quartzite or dolomite whose beds during the period of their compression were folded and sheared and now often stand on end.

Some of the special features of the Starksboro area have been described by N. C. Dale.[1]

The western wall of the valley is formed by the eastern face of Hogback and is marked by numerous scarps. The mountain is broken by transverse faults along which erosion has worked to give a serrated skyline to the ridge. Less prominent scarps occur to the east.

A feature to be noted is the apparent absence of the so-called interbedded series, which is a condition apparently to be correlated with thrust displacements which elevated older rocks against younger ones and not necessarily with the original absence of these beds over the area in question.

The rocks forming the hills to the east of the Starksboro road were not inspected in Starksboro township, except in a small area around South Starksboro village, which will be more conveniently described in connection with Bristol township.

Panton Township.

(Port Henry topographic sheet.)

Location. Panton borders the lake and lies between Ferrisburg on the north and Addison on the south. Its eastern boundary is formed by a portion of Otter Creek which separates it from the town of Waltham.

[1] Twelfth Report of the State Geologist, p. 43.

General description. In Panton the hard rocks are extensively concealed by surface material, and wholly so over the central portion of the township west and east of Dead Creek. In the western part, outcrops are confined to the lake shore and to a low ridge that lies between it and the road running from north to south across the township, through Panton village, and in the eastern part to scattered exposures to the west of Otter Creek.

The shore section beginning in Ferrisburg, two-thirds of a mile north of the Panton line, shows black shales pitching northerly which yielded scattered graptolites and brachiopods. These shales southward pass conformably into others with more numerous limestone bands and these are underlain conformably by thinly-bedded limestones full of characteristic Trenton species. The pitch of these various beds is in a general northerly direction. Southward is thickly-bedded, more massive limestone which resembles the Black River. The so-called Black River beds are somewhat folded so as to give at some places a westerly dip and an unusually massive appearance when viewed from the west. Southward are other massive limestone beds of different lithology and strongly brecciated. These rocks gave two small *Maclurea*-like coils on the weathered surface and it is thought that some Chazy rocks are at this place involved in the shore section. The brecciated limestone southward lies against black shales which are somewhat crushed. The contact is a short distance north of Arnold Bay. From this contact the black shales continue southward for a short distance with southerly pitch, and then, with change of pitch to north, to and around Arnold Bay, where they form the small promontory on its southern side.

The structural relation of the brecciated limestone to the shale, north of Arnold Bay, is far from clear. There is no doubt that the limestone is much older than the shale. The crushing of the latter near the contact seems slight, but if taken with the other disturbance shown by the southward tilting of the shale beds, it is possible to reconcile the conditions with the idea of an upward movement of the older rock into the shales which was probably preceded by brecciation of the limestone at depth. The folding shown by the somewhat massive, so-called Black River beds north of the brecciated limestone indicates that the rocks have been under compression and that, therefore, the contact in question is probably one of thrust.

East of Arnold Bay and the shore road is a low ridge. Just east of the shore road and south of the one running from Arnold Bay to Panton village are low ledges of what appeared to be Black River beds dipping easterly. Farther south along this ridge are numerous outcrops of what appeared to be Chazy beds and still farther south, others which appear to be part of the Beekmantown. Eastward to the west of and sometimes along the road running south from Panton village the Chazy rocks form an

almost continuous outcrop for over two miles and extend into Panton village. In the village, rocks that appeared to be of Black River age lie on the east side of the road, north and south of the one running to Vergennes. *Columnaria* was found in bowlders, but not in place.

From the meridian of Panton village eastward the surface is formed of clay and outcrops are lacking as far east as the low ridge about two miles east of Dead Creek.

In the southwestern part of Vergennes at a road metal quarry is dark gray, magnesian limestone which is conspicuously brecciated at some places. The rock is like that at the falls in the city and is probably a part of the Beekmantown by comparison with rocks in the Shoreham section. Farther south along a road running west of this quarry are outcrops of gray, magnesian rock and quartzite which resemble as much as anything in the region the rocks of Mt. Independence in Orwell, and seemed to the writer, without much doubt, to represent the lower part of Brainerd and Seely's Beekmantown and their so-called "Potsdam" as found in Shoreham. The outcrops of these rocks are, however, few and of small extent and the correlation is tentative.

For the rest, little may apparently be learned of the hard rock underlying this township.

If, as seems likely, the rocks in the eastern part of the township are Lower Beekmantown and those to the west beneath the clay are shales, the former have probably ridden over the latter by thrust much as they have north of Highgate Springs and also to the south in Shoreham and Orwell. The massive rocks in the western part of the township probably represent an independent upthrust into the younger shales.

Waltham Township.

(Port Henry and Middlebury topographic sheets.)

Location. Waltham is separated on the west from Panton and the northeastern part of Addison, which lies south of Panton, by Otter Creek. On the north it is bounded by Vergennes and part of Ferrisburg and on the east and south by New Haven.

General description. Waltham is distinguished topographically by the considerable elevation known as Buck Mt. Description may conveniently begin with the rocks lying between Otter Creek and the mountain.

A road to Weybridge runs directly south from Vergennes on the west side of Buck Mt. About a mile south of Vergennes, between the road just mentioned and another running east of the mountain to New Haven Junction, is strongly sheared, blue limestone of probably Trenton age. Fossils have largely been destroyed. A half mile farther south along the same meridian and east of the Weybridge road is very much mashed limestone

having the lithological characters of the Chazy and often carrying numerous small indistinguishable fossils and recognizable specimens of *Girvanella*. The rocks have been sheared, but a general easterly dip may be discerned. Along the strike of the beds the dip changes from a high to a moderate angle. East of these Chazy rocks are outcrops of Trenton limestone beds also dipping easterly.

Eastward towards the road running from Vergennes to New Haven Junction, beds of limestone form an anticline along meridians which are occupied farther south by the Red Sandrock of Buck Mt. The limestone is not like the Trenton beds just west of it, but in its general characters more closely resembles the dove-gray beds carrying yellow-weathering or chamois-colored layers and patches which are intermingled with interbedded quartzites and dolomites in the areas farther east. It lies on the meridians of the Chazy limestone at Marsh Hill, east of the city of Vergennes. It was apparently regarded as Trenton by Seely and is apparently so shown on his "Geological Map of Addison County" (see Seventh Report of the State Geologist), but this map fails to depict in any detailed or accurate manner the various rock outcrops in Waltham.

North of Buck Mt. a cross road joins the Weybridge and New Haven roads. South of this cross road, along the one to Weybridge, Chazy limestone, dipping easterly and carrying *M. magna* and *Girvanella* forms numerous outcrops. South of these Chazy beds on the west side of the road, opposite the school house, is somewhat sheared, Trenton limestone with many surface markings of fossils. *Prasopora* was found at this locality. The beds dip easterly and are filled with many small veins of calcite. A mile to the south on both sides of the road, beds of Chazy limestone, dipping easterly, form conspicuous ledges. On the east side of the road the rock is visibly sheared, but its fossils are distinct and included distorted specimens of *M. magna* and many specimens of *Girvanella*. East of these beds are much altered Black River rocks, full of small veins of calcite, but still showing the characteristic surface markings of the Black River beds of the lake region. The Black River beds dip easterly. Some of the soil-covered spaces which now separate the Chazy and Trenton outcrops may be underlain by Black River rocks.

The various rocks along the Weybridge road just described belong to the lake series. They are the southward extension of similar rocks around the city of Vergennes and those which lie north of the city in Ferrisburg. All the various kinds of rocks are visibly sheared at some places and show other effects of compression On the southwestern side of Buck Mt., massive Chazy beds may be followed a half mile east of the Weybridge road and seem to be repeated across the strike as though piled on each other by successive thrusting, but in the presence of such ap-

parent repetition of beds in this region it is not always easy to decide whether the conditions are due to thrusting or normal faulting, even when there can be no doubt that as a whole the rocks involved have been disturbed by thrusts.

The rocks along the Weybridge road are on meridians to the east of those occupied by the brecciated, gray, magnesian limestones at Vergennes falls and the similar rocks south of the city. From the fact that north of Vergennes the Chazy, with easterly dip, extends to meridians west of the falls makes it difficult to visualize the relations of these various massive rocks to each other. It seems probable that in a good many cases, massive Lower Ordovician strata broke at depth and were shoved upward into younger rocks in such way that the younger beds on one side were underthrust and on the other overthrust. The horizontal component varied. The brecciated condition of the rock at Vergennes falls and south of the city may be the expression of internal deformation within the Beekmantown rocks on either the underthrust or overthrust border of the ruptured mass. The rocks in eastern Panton which have been described and regarded as probably representing the Lower Beekmantown may have underthrust the rocks along the Weybridge road, in a general sense, and have overthrust the shales which are thought to lie to the west of them.

It is interesting to note that the calcareous rocks in eastern Panton and the western part of Waltham are on meridians occupied by the Red Sandrock formation of Snake Mt. in western Weybridge and the southeastern part of Addison.

East of the Weybridge road passing west of Buck Mt., the calcareous rocks above described in general lie at the base of a series of scarps that bound the mountain on the west. The drift that has been piled against these scarps conceals contacts between the limestone and the Sandrock. The scarps mark planes of faulting; but it is not clear whether the present structural relations of the rocks involved are due to reverse faulting and modifications simply from erosion, or whether primary thrusts have been modified by tension faulting as well as by erosion.

East of the scarps the surface of the mountain slopes gradually eastward across the eroded edges of red quartzite beds which dip gently to the east. East of the mountain, in the western part of New Haven township, the surface is generally covered with drift, but there are some exposures of red quartzites along the direct road from New Haven Junction to Vergennes.

In the southeastern corner of Waltham are interbedded members of the Lower Cambrian series which are probably to be thought of as stratigraphically above the red quartzite forming the eastern slope of Buck Mt. For the most part these members of the interbedded series, which carries some red quartzite, dip to the east, but on their western margin a slight westerly dip

was noted indicating a small amount of flexure in these rocks. These interbedded dolomites and quartzites join southward with others in New Haven township which will be described beyond, and the red quartzite of Buck Mt. also extends southward with reduced elevation into New Haven at the south.

New Haven Township.

(Middlebury topographic sheet.)

Location. This township is one of irregular boundaries. In general it is bounded by Waltham on the west, by Ferrisburg and Monkton on the north, by Bristol on the east and by Middlebury and Weybridge on the south.

General description. In a small jog in the very northwestern part of the town are outcrops of Chazy limestone which are the southward continuation of the Chazy beds along the Weybridge road in the southern part of Waltham. The rocks carry Middle Chazy fossils and dip to the east.

A mile to the south of these rocks is an assemblage of dove-colored limestones, with buff-gray layers which now frequently appear as patches among their associated dove-colored beds. These rocks are not like the Chazy beds just north of them; but are somewhat like the calcareous rocks lying north of Buck Mt. and very much like other rocks found on meridians farther east, more or less intermingled at the present surface with Lower Cambrian rocks and which are very abundant over large areas in the townships of Weybridge and Middlebury. In northwestern New Haven these beds are usually much disturbed, but at some places may be seen to have easterly dip. In their various lithological features these rocks are not easily correlated with any of the members of lake series proper; fossils are absent or obscure and their age has been much of a puzzle to all students of the region.

A few rods north of the junction of the road from Addison village to New Haven Junction, and the one from Vergennes to Weybridge passing west of Buck Mt., members of this formation of dove and gray rocks rest on crushed and sheared, bluish-black, shaly limestone that has strong resemblance to the Trenton. The contact may be plainly seen on the eastern side of the Vergennes road. It seems to be a thrust contact. About a half mile to the west on the north side of the Addison road are graptolite shales with members of the dove and gray series forming the surface above the shales which are exposed in a cut in the bank of the road. East of the dove and gray beds is red quartzite which extends south from Buck Mt. Farther to the east and southward the hard rock passes under clay or drift.

About a mile and a half east of Otter Creek and the outcrops just described is a low ridge formed by the interbedded

rocks of the Cambrian, which are the direct southward extension of the similar rocks in the southeastern part of Waltham and which still hold to a gentle easterly dip. Traced southward these interbedded rocks pass under drift for a short distance. Then along the same meridian are scattered outcrops of gray, siliceous dolomite which continue to within a mile and a half of Weybridge village.

Northeast and east of Weybridge village, to the west of and along the railroad track, are numerous exposures of the dove-colored rock and its buff-gray associate. In their outcrops about a mile southwest of Spring Grove Camp Ground, these rocks frequently stand on end and show evidence of extreme compression. Similar rocks occur southwest of New Haven Junction, where they show the same evidence of compression and are strongly sheared.

East of the Rutland R. R. track at numerous places, over a strip about a mile and a half wide extending from the northern to the southern boundary of the township, are exposures of more or less striped or marbly limestone. Two miles north-northeast of New Haven Junction, near the Ferrisburg line, outcrops of gray, siliceous dolomite or interbedded dolomite and quartzite at places roughly alternate across the strike with outcrops of striped blue or marbly limestone. The structural relations are very obscure, but at places there seems to be suggestion that the marble lies on the dolomite and at others that the interbedded rocks have been thrust over the marble.

The surface of the hill just east of the quarry of the "Green Mountain Lime Works," gives massive, striped bluish and gray rocks interbedded with some siliceous layers and others that weather to a grayish-buff. The gray rock carries obscure coils, but a careful scrutiny of weathered surfaces did not give anything definite. In the quarry of the lime works the rock is generally more or less massive and crystalline and is practically a marble. Planes of stratification are visible, but the beds are much deformed and dip and twist in various directions. In the fields near the quarry, in what appear to be surface exposures of rocks like those in the quarry, are rocks quite similar to those just described for the hill east of the quarry.

Northward across the road from the quarry, white, marbly limestone is intermingled with gray dolomite. Still farther north, along the so-called "Plank road" in the southwestern corner of Ferrisburg, white, marbly limestone lies south of the road, just west of a mass of gray, siliceous dolomite showing bedding well marked, and on the north side of the road, on the same meridian with the marble, is a low ridge composed of interbedded quartzite and dolomite, at this place largely quartzite, showing a gentle anticlinal buckle pitching gently to the north. A fourth of a mile to the west is gray dolomite dipping at a low angle to the east;

and about the same distance to the east is gray dolomite again, which northward along the same meridian gives place to interbedded rocks lying nearly flat.

The field relations in the absence of definite contacts do not permit positive statement of structure; but at the time of inspection it appeared that the primary relation was that of marble resting on Cambrian rocks and that the latter had been thrust against and sometimes over the former. It will appear from later discussions that the primary relation of the marble probably was that just indicated and that in several cases the rocks, whether massive dolomite or interbedded dolomite and quartzite on which the marble lay, were broken and thrust over the marble.

Eastward towards Bristol, along the "Plank road," in the extreme southwestern corner of Monkton, but practically on the New Haven line, are ledges of massive dolomite forming the low, southern portion of Monkton ridge. Southward these rocks disappear beneath Cedar Swamp; but south of the swamp, on the same meridian, and just south of the Bristol R. R. track, begins a ridge of the interbedded series. Near the crossing of the New Haven-Bristol road and the railroad track are beds of red quartzite which dip gently to the west. Slightly to the southeast is a distinct scarp on the western side of a considerable hill of interbedded dolomites and quartzites. Two-thirds of a mile east, across a low area, is another hill or ridge of the interbedded rocks, which on the western side are terribly jammed and puddled. Eastward the beds undulate and stand at various angles of dip, but at the summit of the eastern slope they may be seen to dip gently to the west. The eastern slope of the hill from these beds down to the road that runs from New Haven Mills northward towards Monkton is drift covered; but southward, northeast of New Haven Mills, is whitish, granular quartzite apparently overlain by gray dolomite. The quartzite outcrops on both sides of the dolomite and dips to the east; the dolomite is sheared so that its bedding is obscured; but at places it seems to be standing on end.

South-southwest of New Haven Mills, south of the river, on the meridian of the quartzites and dolomites north-northwest of the village, is another ridge of the interbedded rocks. On the west of this ridge the rocks dip westerly, but on the eastern slope they form the distorted, pushed-up eastern limb of an anticlinal fold. The effects of compression at this place beggar description. The often somewhat massive quartzite beds are jammed into Z-shaped folds and strongly sheared withal and wave back and forth along the strike. The structure is identical with that shown by similar rocks east of Brandon, as elsewhere described, except that the jamming is more severe. The interbedded rocks may be followed along this ridge southward to the Middlebury line and have anticlinal structure throughout. Near the southern

boundary of the township these rocks are only a mile from the quartzite scarp along the edge of the plateau, from which they are separated by the ledges of massive, gray dolomite forming the hill known as the "Cobble."

North of New Haven Mills, partly in Bristol, are several low, detached hills of gray dolomite, some of which show scarps on the west. Sheared, gray, siliceous dolomite forms the bed and banks of the river at New Haven Mills.

The interbedded rocks forming the hill with the prominent scarp southeast of New Haven village join at the surface with similar rocks along the road that runs directly south from the village along which they outcrop through a distance of two miles. One-half mile west of the road and about a mile south-southwest of New Haven village are outcrops of bluish-white marble, flanked on the west by striped bluish limestone with spots of marbly rock, all dipping easterly and all marked by strong flow-shearing. The striped rock has much superficial resemblance to some Middle Chazy of the lake series. No fossils have survived the severe deformation of the rock. About a half mile west of these outcrops are others of similar rock on the east side of the road from Spring Grove Camp Ground to New Haven village, and south of the latter are still other outcrops of bluish limestone somewhat involved with buff-weathering layers.

Two miles southeast of Spring Grove Camp Ground, in the angle of the roads, are outcrops of bluish and marbly limestone intermingled with fragmentary patches of the interbedded series. Since these rocks lie on the meridians of the interbedded rocks farther north it seemed likely that the marble had actually been overridden by the Lower Cambrian rocks. The relations again are similar to those among the interbedded rocks and the marble around Brandon.

On the meridian of the rocks described in the last paragraph, south of New Haven River and west of Muddy Brook, is a ridge which extends southward into Middlebury township. Great confusion prevails among the surface rocks along this ridge. At its northern end, which is the portion included in New Haven, on the east slope, gray dolomite is intermingled with striped blue limestone. Westward over the summit the striped blue limestone is intermingled with patches of interbedded dolomites and quartzites, the latter often forming exposures of considerable size, with well-defined bedding and dip. In some places the members of the interbedded series lie flat, in others they dip to the west and in others the structure may not be made out. A survey of the hill showed that quartzites and dolomites are often involved with the limestone in such a way as to give the appearance of being interstratified. The surface is greatly broken by gullies and knolls of various dimensions. In some places the striped blue rock

shows in massive ledges; in others the rock is apparently all gray, siliceous dolomite.

The secondary structural features are very complicated; but the general field relations seemed to point to involved thrust relations like those which have been described for the region around Brandon. Similar conditions will be described for Middlebury in subsequent pages.

No fossils were found although it seemed as though they should be and diligent search was made.

East of this ridge, near Muddy Brook and on the township line, is a marble quarry, known as "marble ledge." Marble also outcrops to the north of the quarry, just south of New Haven River. Gray dolomite forms the eastern wall of the quarry and marks the surface along which the marble has been quarried. Again, the conditions are precisely like those in some of the quarries around Brandon.

Wing was reported by Dana[1] to have found an *Orthoceras*, resembling *O. primigenium* Hall (a Calciferous form), in rocks, a little way south of the quarry, east of the brook, in Middlebury. On the basis of this fossil the rocks were assigned to the Beekmantown by Dana and later by Seely. In fact all the various rocks that have just been described for the southwestern part of New Haven were called Beekmantown by Seely. A great deal of the marbly and striped limestone in the writer's opinion has more lithological resemblance to the Chazy and it is certain that Lower Cambrian dolomites and interbedded rocks are involved with the marbly limestone. The writer tried to find the spot which Wing, Dana and Seely visited, following carefully the directions given by Dana (loc. cit.) but failed to note the outcrop.

Dana further mentions discovery by Wing of other fossils a half mile northwest of the *Orthoceras* locality, and apparently on the eastern slope of the ridge west of Muddy Brook. At this locality "and apparently in the same formation with the last, there are specimens resembling *Ophileta compacta;* there was also found here a large *Maclurea.*"

"About a mile southwest of the Middlebury quarry and thirty or forty rods west of Mr. E. Kirby's residence, in an old orchard, several distinct convoluted shells were seen on a dark, siliceous limestone dipping west. The beds are probably Calciferous."

North and south of Beldens, in the fields east of Otter Creek and in the bed of the river itself, are extensive exposures of usually distinctly bedded gray and buff-weathering rocks which are different from the striped blue and marbly limestones that lie east of them. These rocks have also been called Beekmantown. They extend southward into Middlebury, where they present interesting field relations yet to be described. The age of the rocks is doubtful; they may be part of the Beekmantown, but in the

[1] A. J. S., vol. XIII, 1877, p. 406.

writer's opinion, Beekmantown has been employed in much too inclusive a way for the more or less altered rocks over the eastern portion of the Champlain lowland.

Bristol Township, including parts of Lincoln Township.

(Middlebury topographic sheet.)

Location. Bristol borders New Haven on the east. Lincoln lies east and southeast of Bristol.

General description. The southern portion of Monkton ridge extends into the northwestern portion of Bristol. Most of the portion of the ridge included in Bristol is made of quartzite, but massive, gray dolomite occurs at the southern end near the New Haven line. South of this dolomite is Cedar Swamp, from which at the south emerge the interbedded quartzites and dolomites of the eastern part of New Haven.

A surface section southward from Monkton ridge into New Haven thus gives with interruptions a succession from quartzite through gray, massive dolomite to interbedded quartzites and dolomites and suggests that this is the usual stratigraphic sequence.

The valley occupied by Pond Brook in Monkton extends southward into Bristol, but its basin character gradually fades southward towards Bristol village owing to the falling off in elevation of the southern portion of Monkton ridge.

Bowlder drift topped by sand plains largely conceals the hard rock around Bristol village west of Hogback Mt. Gray, siliceous dolomite, dipping westerly, outcrops northwest of the village and southwest of it, west of "Bristol Flats," other dolomite marks the northward extension of the rocks at and north of New Haven Mills.

South of Bristol village, to the east of Bristol Flats and just east of the road that runs along the eastern edge of the Flats, the rock is largely a gray or brownish-gray, granular quartzite, dipping easterly; but eastward at places near the foot of South Mt. the quartzite dips westerly. Southward, gray dolomite forming the northern end of "Cobble" hill, conceals the quartzite.

In the township of Bristol, west of Hogback and South Mt., the underlying rock is thus seen to be quartzite with overlying dolomite which form a shallow, synclinal fold, suggesting that the valley of Pond Brook is primarily a syncline which has been modified by faulting.

In Bristol, as in Monkton, the western face of Hogback shows a succession of scarps along the strike. The rock along these scarps, which were inspected at many places, is essentially a quartzite which is usually strongly sheared and much like some of the rock that has been described for the hilly land east of St. Albans and Milton. In spite of shearing the bedding is visible

and dips to the east. The easterly dip is well shown on the mountain at the ledge known locally as "Table Rock."

New Haven River enters the lowland through a gap between Hogback and South Mt. Along this pass the quartzite may be observed at many places dipping easterly and the southern end of Hogback may clearly be seen to be bounded by a series of scarps marking fault displacements across the strike. The river has availed itself of these lines of weakness.

At Ackworth, ledges of quartzite are abundant. The dip is easterly at a small angle and the rocks exhibit little or no internal deformation. There is a slight northerly pitch. On the road towards West Lincoln, about one-third of a mile east of Ackworth, the dip is westerly.

The valley of Beaver Brook and Baldwin Creek north of Ackworth is the southward continuation of the valley of Lewis Creek in Starksboro. It is primarily of synclinal structure, but is modified by faulting. The eastern face of Hogback shows scarps marking faults. A mile and a half north of Ackworth, gray dolomite on the west side of the road dips westerly.

Quartzite continues north from Ackworth east of the Starksboro road. At the western end of the gorge of Baldwin Creek is strongly sheared rock, much like that on the western side of Hogback. In the bed and banks of the stream a fourth of a mile east is blackish phyllite which is probably a sheared muddy member of the quartzite formation. Two-thirds of a mile farther east, in the north bank of the gorge, are impure quartzitic and calcareo-siliceous beds greatly sheared and crushed, which have some resemblance to the interbedded series found in the lowland to the west of the plateau. At South Starksboro the prevailing rocks are impure, coarse schists which were interpreted as probably originally forming impure basal portions of the overlapping Lower Cambrian series.

A mile southeast of South Starksboro, on the side of the road near a school house, was seen a small exposure of interbedded quartzite and calcareous rock. East of these beds in the fields are others of quartzite lying nearly flat.

The interbedded, impure quartzites and calcareous rocks west and southeast of South Starksboro seem to resemble the interbedded series of the lowland west of the plateau closely enough to be regarded not as precise equivalents perhaps, but as related members of a common formation. It would seem that in the process of overlap such rocks were carried eastward into what is now the plateau, just as gray dolomite was also carried at some places.

The quartzite exposed in the bed of New Haven River, southeast of Ackworth, gives place southeast of West Lincoln to gneissic rocks that are different from the sheared rocks that seem more or less definitely to belong to a formation which

originally consisted of various kinds of sediments and which is probably of Lower Cambrian age. Similar gneisses were noted near the river at Lincoln Center and in South Lincoln and are regarded as probably pre-Cambrian and as forming a part of the floor of deposition of the quartzite-schist-dolomite formation.

Three and a half miles south of Bristol village the "little notch road" leaves the lowland and climbs over the mountain to South Lincoln. The western portion of the road cuts through the southward extension of the quartzite of the western part of South Mt. From places along the road, east of the front range of hills, they may be seen to be bounded on the east by scarps, to the east of which the surface is lower. The suggestion which the topography gives of down-faulting on the east of the front range is supported by the occurrence of considerable exposures of gray dolomite along the road towards South Lincoln. The dolomite is intermingled over large areas with micaceous, quartzitic schist, which apparently weathers fairly easily, but it did not appear from any outcrops which were noted that the schist is interbedded with the dolomite. The gray dolomite is lithologically much like that west of the plateau. In some of its outcrops it occurs in undulating folds sheared across the bedding. This dolomite was interpreted as the extension eastward into the plateau of the dolomite that is found in what is now the lowland to the west of it, and as part of the Lower Cambrian series.

Around South Lincoln in the beds of streams, foliated, gneissic rocks not easily interpreted as sheared members of the Cambrian formation were noted and at the time of their inspection seemed to be probably a portion of the pre-Cambrian formation of basal gneisses. No attempt was made to trace the quartzite-dolomite-schist formation into the eastern part of Lincoln.

While some of the members of the formation, which is regarded as Lower Cambrian, in their occurrence in the mountains are not very much deformed internally, others of them are and in some places shearing or crushing is severe, and gneissoid or schistose structure is common. The most severely sheared types might be confused with other rocks and assigned a different age and possibly to an older series, without careful discrimination; but it seemed that any of the gneisses which could be interpreted as probably older than Cambrian are sufficiently different from sheared and altered younger rocks to be fairly easily distinguished, at least within the areas examined by the writer. Such might not be the case farther east in the mountains.

Addison Township.

(Port Henry topographic sheet.)

Location. Addison township borders the lake and lies south of Panton. It is bounded on the east by parts of Waltham and Weybridge and on the south by Bridport.

General description. Like Panton, a large part of the western portion and most of the central portions are covered with clay. Outcrops are, therefore, practically confined to the lake shore and the somewhat hilly eastern part.

From the Bridport line northward along shore as far as Chimney Point is clay. At Chimney Point are beautifully glaciated ledges of Chazy with the beds dipping at a low angle to the west. Similar beds with about the same dip occur to the northeast, on the north bank of Hospital Creek.

North of Hospital Creek, to the west of the Chazy outcrops, on the lake shore, are thinly-bedded limestones, weathering gray but bluish on fresh surfaces, clearly derived from limy muds, and full of characteristic basal Trenton fossils. The beds also dip westerly and at an angle about like that of the neighboring Chazy rocks at the east. They have apparently a slight northerly pitch.

These Trenton rocks are succeeded along shore northward by more or less regularly interbedded, blackish limestone and shale. The limestone members contain Trenton fossils, including *Prasopora,* and the series plainly marks a transition from the "basal" Trenton beds into rocks that are more notably shaly and which continue along shore to Potash Bay. The dip throughout is gently to the west. Graptolites were found at numerous places in the shales, but *Triarthrus becki,* so common in the shales in the northern part of the lake region, was not seen. The shore section from Crane Point to Potash Bay is about three miles long. The dip is so gentle that the rocks lie almost flat. They seem to be broken hardly any, if at all, by displacements and as a whole give a considerable thickness of apparently conformable beds ranging from the base of the Trenton well up into the shale formation.

East of the shore section the hard rocks are usually beneath clay; some apparently Trenton rocks outcrop along the road north of Hospital Creek.

In general the rocks along shore in Addison appear to form the western limb of a gentle anticlinal fold. The apparent structure permits the interpretation that the basin of the lake west of Addison was excavated in shales that conformably overlay the rocks that lie along shore and that similar shales extend eastward beneath the clay. In other words, along the Addison shore there is little or no suggestion of overthrust of older rocks on the shales such as is seen in many other places along or near the lake. If

the rocks around Chimney and Crane Points constitute a conformable series, Black River beds should intervene between the Chazy and Trenton, by analogy with conditions at other places in western Vermont. There are some outcrops on the road north of Hospital Creek which indeed suggest the Black River, but if these rocks are generally present they are for the most part concealed.

The eastern boundary of Addison zigzags through the mass of Snake Mt. which lies partly in this township and partly in Weybridge. North of Snake Mt. the eastern boundary follows Otter Creek to the Panton line.

The higher portions of the mountain are in Addison. The rock is chiefly red quartzite, like that of Buck Mt. The surface of the mountain falls off abruptly northward and gives place to a clay-covered lowland. The western face of the mountain is marked by scarps, against which at places rest banks of glacial drift.

Along and near the road that runs just west of the mountain are outcrops of limestone which may now be described.

From Addison village a road runs eastward to Weybridge, passing north of Snake Mt. About a mile east of the village another road runs southward just west of the mountain. East of this road on the northwestern slope of the mountain are beds of shaly limestone lying nearly flat but which have perceptible easterly dip and are rather conspicuously sheared. These outcrops yielded a few Trenton fossils. Perhaps 150 rods farther south, along the roadside, are ledges of Chazy limestone also dipping easterly and carrying characteristic fossils. The Chazy continues southward for a fourth of a mile and is flanked on the east by Black River beds. A mile to the south on the same meridian with these rocks are shaly limestones which outcrop intermittently along the road to the Bridport line.

To the west of the road just followed is another parallel with it which runs through Addison village. Sheared limestone carrying Trenton fossils and dipping easterly outcrops one-half mile north of the Bridport line and a mile farther north are ledges of Chazy with easterly dip.

The calcareous rocks lying west of Snake Mt. apparently form a monoclinal series dipping easterly, with the Chazy at the base overlain by Black River and sheared Trenton limestone. While the outcrops are scattered, the field relations among them permit the interpretation just given and also the inference that the beds are mainly conformable, although possibly displaced somewhat with reference to each other. About six miles to the west the same series dips in the opposite direction. It is not easy to imagine that the rocks along the lake shore and those west of Snake Mt. form the limbs of a common anticlinal arch, for the dip is so low that in the wide interval between them there

seemingly should occur other outcrops of the heavier members, which does not seem to be the case. If there were several folds over the interval that now separates these rocks there should be intermediate ridges which do not occur.

Although along meridians, now occupied at the surface in Addison by clay, Chazy rocks are exposed in Panton, this circumstance does not seem to justify the inference that the clay in Addison is directly underlain by Chazy limestone; for in Shoreham to the south these meridians show the shales as the surface rock. As will be shown beyond, it is probable that the clay over central Addison and Bridport is underlain by shales, and that the older limestones are deeper down. The key to the structural relations among the various rocks in Addison seems likely to be found in the major kind of deformation which the region has suffered. Snake Mt. is primarily an unlift of the older rocks which have also been thrust to the west. The limestones west of the mountain have probably suffered similar deformation. The quartzite of Snake Mt. in Addison and the calcareous rocks west of it are on meridians occupied by probable Beekmantown farther north in Panton.

Weybridge Township.

(Port Henry and Middlebury topographic sheets.)

Location. Weybridge is bordered on the west by parts of Addison and Bridport, on the north by parts of Addison and New Haven, on the east by parts of New Haven and Middlebury, and on the south by Cornwall.

General description. The eastern slope of Snake Mt. descends into the western part of Weybridge. All the outcrops inspected west of the Lemon Fair are of Red Sandrock, which dips to the east.

Clay forms the surface over much of the valley of the Fair, and that of the Otter west of Weybridge village.

East of the Fair, at varying distances from it, the surface rises to form Weybridge Hill, which is a ridge of much the same pattern as that of Snake Mt., but of lower elevation. On the west of the ridge are steep slopes and numerous softened scarps from whose summits there extends eastward an irregular surface which in general descends to the bed of Otter Creek.

Near the Cornwall line the steep western margin of the ridge forms what is known as "The Ledge." It is marked by a scarp which extends southward into Cornwall. At "The Ledge" the rock is massive, gray limestone without well-defined structure or dip. It yielded no fossils. The same rock continues northward to within a half mile of Center, a small settlement two miles south of Weybridge village.

Southwest of Center, along a road that descends diagonally across the steep western slope, is black phyllite forming a distinct scarp, to the west and east of which lie calcareous rocks much like those of "The Ledge." The phyllite forms the northern termination of what was designated in the Vermont report and by later observers as the "central belt of slate," and has been regarded as of "Utica" or "Hudson River" age. In the writer's opinion, the rock has little resemblance to the so-called "Utica" of the lake region proper and does not suggest an altered derivative of that formation. On the contrary it is entirely similar to phyllite occurring in Cornwall at the south, which will be described beyond, and which seems clearly to be the northward extension of the phyllites of Whiting and Sudbury, which are regarded as much older. The field relations southwest of Center might possibly suggest that the phyllite is interstratified with the limestone that borders it on the west and east; but such relation is hardly possible if the phyllite is what the writer conceives it to be. The general relations point to displacements and it seems most likely that the phyllite was thrust into the limestone.

North of Center towards Weybridge, east of the road, is strongly sheared, calcareous rock of quite uncertain correlation which lies to the west of numerous outcrops of somewhat marbly, dove-gray limestone associated with chamois-gray patches which are badly crumpled and mixed up.

Farther north, south of Weybridge village, what now appears as massive, gray, dolomitic limestone forms scarps east of the road to Center. The rock has been under compression but is not conspicuously sheared. No fossils were found. In lithology it resembles somewhat the rock at "The Ledge" near the Cornwall line and to some extent also the gray rock that is found at the east in association with the quartzite. Similar rock forms the falls and banks of the river at Weybridge village. The gray dolomite at Weybridge village is on the meridians of that which occurs two miles north of the village in New Haven and the latter, as previously shown, with slight surface interruption joins the interbedded dolomites and quartzites southeast of Buck Mt.

According to Dana, Wing found at Weybridge upper falls, on the west side of the slate, presumably the northward continuation of the phyllite found farther south, "Rhynchonella beds" (called Chazy) lying beneath "Sparry limestone" (Trenton). The "striped stratum" (Chazy) was described as full of fossils. This locality was not seen by the writer, but became known to him from subsequent reading of Mr. Wing's discoveries in Vermont.

Southeast of Center, on the road towards Middlebury and in adjacent fields, are ledges of striped limestone which suggest the Chazy. Farther south towards Middlebury along the road, and over the part of the township lying east and southeast of Center

and west of Otter Creek, are abundant ledges of sheared, dark bluish limestone resembling Trenton. These rocks apparently occupy a broad band in eastern Weybridge, west of Otter Creek. Fossils were not found in Weybridge. Later, on a trip made over territory southwest of Middlebury village in northeastern Cornwall, Trenton fossils were found in similar sheared, dark bluish limestones which lie on meridians practically marking the western boundary of the similar rocks in Weybridge.

The Otter which flows north from Middlebury village forms part of the eastern boundary of Weybridge and separates it from Middlebury. On the Middlebury side the sheared, bluish, so-called Trenton rocks give place to marbly, dull gray rocks with associated yellowish or chamois-gray layers which form a broad band in this part of Middlebury township and join at the north with similar rocks in the southwestern part of New Haven, which have been described.

From west to east across Weybridge the rocks, broadly speaking, are not disposed in folds, but in an irregular sequence probably due to reverse fault displacements along the strike, with probably some imbrication due to lateral thrust. The latter is not clearly exhibited by a definite contact in Weybridge, but in Middlebury village below the falls a good overthrust contact may be seen, as will be later described.

Middlebury Township.

(Middlebury and Brandon topographic sheets.)

Location. On the west Middlebury is separated from Weybridge by a portion of Otter Creek, and is further bounded by a part of Cornwall. On the north it is bounded by New Haven and a part of Bristol, on the east by Ripton, and on the south by Salisbury. The eastern portion of the township includes a strip along the western border of the Green Mountain plateau.

General description. The gray limestones and interbedded, buff- or chamois-weathering layers which lie just east of the Otter, north of Middlebury village, have already been mentioned. They give prominent exposures on both sides of the railroad track south of Beldens, and between the track and the river southward towards Middlebury village. In the village below the falls they are in juxtaposition with strongly sheared, limy shales and at one place show a good thrust contact, with the shale which has been pictured by Seely. Seely called the shale Trenton and the overthrust rock Beekmantown.

South of the latitude of Beldens these rocks continue eastward at the surface to the road running from Middlebury village to New Haven Junction. Southward, west of Chipman Hill and east of the railroad track, they largely pass under drift.

North of Chipman Hill a cross road leaves the main road between New Haven and Middlebury and runs one-third of a mile due east and then bends southeastward. South of this road at the northern end of Chipman Hill is sheared limestone which corresponds closely with rock in Ferrisburg to the northeast of the city of Vergennes and which near Vergennes by the fossils in several places and by the lithology in others, was correlated with the Chazy. East of the cross road, after it makes it bend to the southeast, is altered, now somewhat crystalline limestone, weathering to a light blue, which suggests the Trenton. It is apparently without fossils at this place. This rock is on the western margin of a ridge which extends from New Haven into Middlebury, the rocks of which at its northern end in New Haven have been described (page 249). In the Middlebury portion of the ridge, west of the road that runs lengthwise along it, is much the same assemblage of rocks found at the northern end. Rocks identified as members of the interbedded series of dolomites and quartzites are more or less intermingled with outcrops of striped or gray limestone and some gray dolomite. East of the road are abundant exposures of gray limestones associated with somewhat yellowish-weathering rocks. These sometimes give place to striped limestone which resembles the Chazy.

Eastward is Muddy Brook, west of which was seen quartzite associated with some dolomite. These rocks lie on a meridian west of the marble at "marble ledge" quarry near the New Haven line. At the quarry the marble is associated with gray dolomite which forms the eastern wall of the quarry.

East of Chipman Hill is a topographic break in the ridge mentioned above. South of this break, a little north of east of Middlebury village, is a hill of camel-hump shape which is geologically a southward continuation of the ridge. This hill presents relations of much interest. On the top of the hill are interbedded quartzites and dirty, somewhat yellowish-weathering dolomites, dipping westerly and not strongly sheared or folded, which apparently lie on bluish-gray or dull gray limestone which seems to be more deformed and altered. This hill seemed to show the interbedded rocks of probably Lower Cambrian age resting on probably younger (Chazy) limestone.

South of this hill a road runs from Middlebury village eastward towards the mountain. The road forks about a mile east of the village, and near the fork gray dolomite is seen to form a fold or "roll" very much like the structure seen at the old quarry southeast of Leicester Junction and at the Norcross quarry south of Dorset Mt. One-half mile east of the fork, on the north side of the road running east, is the quarry of the Middlebury Marble Co., now worked for lime. The marble is not a very good commercial stone, but in all essential particulars is like the marble in the quarries around Brandon. The marble continues

eastward for a short distance at the surface and then gives place to gray, siliceous dolomite and interbedded quartzite and dolomite, the latter dipping easterly at a high angle. The dolomite and interbedded rocks lie along meridians occupied both to the north and south by similar rocks. Eastward is other gray dolomite and then the scarps in the quartzite along the edge of the plateau.

About two miles south-southwest of Middlebury village are ledges of dove-gray or bluish rock which were regarded as probably of Chazy age. The noteworthy structure is the strong shearing. The dip is obscure; in some places it seemed to be to the west; in other places the beds appeared to stand on end. These outcrops are a mile east-northeast of other ledges in eastern Cornwall which carry Trenton fossils, including *Prasopora*.

Two miles directly east of the rocks called Chazy, which were just mentioned, and south of the road from Middlebury village to East Middlebury, are two short ridges composed chiefly of dove-gray or bluish limestone carrying patches of yellowish-gray rock. Similar rocks occur one and a half miles to the southwest, just west of Otter Creek on the road from Farmingdale to Cornwall.

At Farmingdale are outcrops of gray, siliceous dolomite like that usually associated with the quartzite along the eastern border of the lowland. This gray dolomite is intermingled with some marbly limestone along the road running from Farmingdale eastward to within a fourth of a mile of the main road from Salisbury to Middlebury. West of East Middlebury village, near the junction of the main roads, are interbedded dolomites and quartzites forming a gentle anticline, the beds dipping westerly south of the road from East Middlebury to Middlebury on one meridian and easterly to the north of the roads on a meridian slightly to the east of the other.

Along the road from East Middlebury to Bristol, a mile northwest of East Middlebury village, is massive quartzite overlain by dolomite, the latter clearly dipping westerly.

In the bed of the river east of East Middlebury village, beds of quartzite dip westerly.

South of East Middlebury is a hill composed of granular, gray quartzite which is a dismembered part of the rock of the plateau.

The geological relations and topographic features in the eastern part of Middlebury township are very similar to those found at many places along the eastern edge of the lowland and in the Vermont valley. They are in all cases apparently of similar genesis. The rocks in the eastern part of the lowland are dismembered parts of the formations of the plateau.

Bridport Township.

(Port Henry and Ticonderoga topographic sheets.)

Location. Bridport borders the lake and lies south of Addison. It is bounded on the east by parts of Weybridge and Cornwall and on the south by Shoreham.

General description. Away from the lake shore in the western part and over the central portions of Bridport, clay usually conceals the hard rock. Outcrops of shale yielding broken graptolites outcrop intermittently along shore from a point near the northern township line southward past Plumies Point to a conspicuous jog in the shore line about one and a half miles north of Crown Point ferry landing.

Near the landing at West Bridport are what appear to be Chazy and Black River beds.

Seely mentioned some exposures of so-called Beekmantown rocks near the head of the West Branch of Dead Creek; but on his map showed such rocks at the head of the East Branch. The writer did not see these rocks, but found flat, clay-covered land around the head of the West Branch. Southward in Shoreham, shales outcrop on meridians occupied by the West Branch in Bridport.

Shales outcrop north and south of Bridport village and at places along the road which runs east from the main Bridport-Addison road just north of the village. Along the second road running east, north of the village, about two miles east of the Addison road, and on the meridians of the Red Sandrock to the north in Addison, are blackish shales which sometimes are strongly folded and sometimes lie rather flat, all marked by well-developed cleavage. Southwestward these rocks give place at the surface to sheared, shaly limestone and these in turn to somewhat massive, plainly bedded limestone, which is not severely deformed internally and which has much the aspect of other rock a mile to the southwest which is clearly older than the shale. The shale is a mile slightly to the west of south of the southward extension of the Red Sandrock of Weybridge into the northeastern part of Bridport.

South of Bridport village a road runs easterly, to the north of Hemenway Hill. Along this road and south of it in the field are blackish cleaved shales, which a mile east of the main Bridport-Shoreham road are succeeded along the road by thinly-bedded, blue limestone with good Trenton fossils. East of these Trenton beds a road runs southerly on the east side of Hemenway Hill. West of this road and just south of the fossiliferous Trenton outcrops are ledges of rock which in its lithology suggests part of the Beekmantown in Shoreham. Farther south on the east slope of the hill are outcrops of rock of more decided resemblance to some of the Beekmantown. The beds dip to the

east and are on meridians occupied by beds correlated with the Beekmantown at Mutton Hill in Shoreham.

The rocks outcropping on the east slope of Hemenway Hill are separated by the flat land along the Lemon Fair River from rocks forming a low ridge in western Cornwall and which appear to be the northern continuation of the rocks of Cutting and Delano Hills in Shoreham, which are considered to be of Beekmantown age, as defined by Brainerd and Seely.

The conditions in the eastern part of Bridport certainly strongly suggest upthrust of older rocks into younger ones, with some overlap of the former. The older rocks are in some cases members of the Red Sandrock series and in others probably of the Beekmantown. Probably Chazy and Trenton beds have in some cases been involved in thrust.

Cornwall Township.

(Port Henry, Ticonderoga, Middlebury and Brandon topographic sheets.)

Location. Cornwall on the west adjoins the southeastern part of Bridport and the northeastern part of Shoreham. It is bounded on the north by Weybridge, on the east by parts of Middlebury and Salisbury, and on the south by Whiting.

General description. The red quartzite of the Red Sandrock series of the Snake Mt. mass projects from Bridport and Weybridge into the northwestern part of the township.

On the meridians of this quartzite, farther south along the western border of the township, is a ridge falling off on the west into the flat land along the Lemon Fair in southeastern Bridport, and sloping more gradually eastward into more or less drift-covered land. The rock in the ridge has been called Beekmantown and certainly has resemblance to part of that formation as described for Shoreham. The dip is apparently generally if not always to the east.

East of Beaver Branch rises another ridge of somewhat similar pattern which is the southward extension from Weybridge into Cornwall of the ridge already described for its northern portion in Weybridge. Its western margin begins at the north in a precipitous scarp known as "The Ledge." The scarp continues southward for a distance of two miles and merges with a more gentle slope northwest of Cornwall village. The beds dip easterly. The rock may be largely Beekmantown, but about a half mile northwest of Cornwall village are beds of dove-gray rock also dipping easterly and apparently stratigraphically above the rocks to the northwest of them. These beds may be Chazy.

Outcrops of Chazy limestone, which in some places show fossils, occur south of the village along the road towards Whiting.

These rocks are succeeded southward by exposures of sheared limestone of uncertain correlation.

The main road going north from Cornwall village forks about a mile and a half north of the village. Along the west branch, near the fork of the road, is black phyllite. Just east of this rock are ledges of sheared limestone which gave good Trenton fossils, as previously described (page 258). The Trenton rocks continue southward to the east of the road through Cornwall village and are intermingled with black phyllite or schist carrying some massive quartzite.

One-third of a mile north of the village a road runs easterly towards Farmingdale in Middlebury. Two-thirds of a mile east of the main road are ledges of quartzite with associated black phyllite which are succeeded easterly by ledges of limestone resembling the Trenton. Fossils were not found. Eastward are beds of sheared rock resembling the Chazy. These presumably Chazy beds form a short, low ridge along the western border of the northern end of Cedar Swamp; the beds dip easterly and carry obscure fossils.

Near the Whiting line a road runs easterly from the main Whiting-Cornwall road towards Salisbury station. Black phyllite outcrops along this road and in the fields north of it, to the west of Cedar Swamp. Observations showed that the black phyllite or schist is frequent north of this road, between the swamp and the Whiting-Cornwall road. It is associated with sheared limestone of uncertain correlation.

Black phyllite was also found along the road running west from Middlebury village, about two and a half miles west of the village and a mile south of the Weybridge line. This phyllite joins that of Cornwall with that of Weybridge.

The relations northeast, east and southeast of Cornwall village are strikingly similar to those found at the northern end of the Taconic range in Sudbury, except that in Cornwall there is less quartzite exposed and more phyllite mingled with the calcareous rocks than is the case in Sudbury, and that the calcareous rocks carry obscure fossils in Cornwall and in other respects seem to be more easily recognized. The phyllites of Cornwall join through the similar rocks of Whiting with the quartzites and schists of Sudbury.

In the early descriptions of the black and lighter colored phyllites and the quartzites which extend north from Sudbury through Whiting and Cornwall into Weybridge they were regarded as of "Utica" (Brainerd and Seely) or "Hudson River" (Vermont Report, Wing and Dana) age. The principal reason for such assignments seems to have been because they are associated with rocks of Trenton age, which are intermingled with them or border them.

The Vermont Report and Wing both recognized that the "central belt of slate" in Weybridge, Cornwall and Whiting is the northern continuation of the Taconic range; but apparently neither considered the possibility that the rocks composing it may be much older than they indicated.

It has already been remarked that the phyllite of Weybridge bears little resemblance to the rocks near the lake. The quartzite occurring with the phyllite in Cornwall and Whiting in such way as to leave no doubt of the common membership of the two in one formation seems to prohibit the inclusion of these rocks with the Ordovician shale. On the other hand, the phyllite and quartzite are so similar to rocks in the Taconic range and at some places along the western margin of the plateau near Brandon that they probably belong to the same formation and to one including the granular quartzite, and are probably, therefore, of Lower Cambrian age.

There may also be said to be some doubt as to the inclusion of all the gray, dolomitic limestone that occurs to the east of the Red Sandrock of Snake Mt. in northern Cornwall, but particularly in Weybridge, in the Lower Ordovician (Beekmantown). On a lithological basis, which is often the only one that may be employed, it would be hard to decide; for some of the gray rock is siliceous and has much the same appearance as the rock associated with quartzite nearer the plateau. The matter is complicated not only by undoubted deformations, but probably also by unusual conditions of sedimentary overlap of Ordovician beds on an eroded surface of Cambrian rocks which included siliceous dolomite, as has been frequently shown.

Shoreham Township.

(Ticonderoga and Brandon topographic sheets.)

Location. Shoreham lies south of Bridport and is bordered on the west by the lake, on the east by parts of Cornwall and Whiting, and on the south by Orwell.

General description. In his first paper the writer briefly discussed certain features of the geology of this township, based upon a personal review of the geological relations described by Brainerd and Seely, and in connection with the geology of the town of Orwell which adjoins Shoreham on the south. The eastern part of the township displays the type section of the so-called Beekmantown of western Vermont. For a detailed description of this section the reader is referred to Brainerd and Seely's original account.[1]

What underlies the flat land along the course of the Lemon Fair River in southeastern Bridport may only be conjectured; but immediately east of this flat area in Cornwall and south of it

[1] Bull. No. 3, Amer. Mus. Nat. Hist., 1890-91.

in Shoreham are rocks which by comparison with those of the East Shoreham section are apparently to be correlated with the so-called Beekmantown. In the very northeastern part of the township the Lemon Fair has trenched these rocks and low cliffs appear in them on both sides of the stream. On the east side, practically on the Cornwall line, and on the road running west from West Cornwall village, a steep westerly dip was noted and the beds are sheared across the bedding. From these ledges a scarp runs southward along the western base of the hill and the prevailing dip along it is apparently to the east. About two-thirds of a mile south of the westerly-dipping beds some Chazy appears to be present on the west side of the road. Southward along the old "Amherst road" to Richville what appear to be Beekmantown rocks may be followed by intermittent outcrops showing easterly dip nearly to Richville. The rocks along this road are the northern extension of those of Delano and Cutting Hills which are included in Brainerd and Seely's Shoreham section of the Beekmantown.

Observations show that the eastern half of Shoreham township is largely formed of Beekmantown which is associated with some older rocks of so-called "Potsdam" age and younger beds belonging to the Chazy and Trenton. Chazy and Trenton beds border the Beekmantown on the east and are involved with it just east of Shoreham village. As Brainerd and Seely clearly showed, the massive rocks have been broken by thrust faults along the general strike of the rocks at several places. By these thrusts the older Beekmantown and underlying "Potsdam" have been fractured so that older beds have moved into and over younger rocks. Prior to or during thrusting, some folding occurred; but the major deformation was that of fracture accompanied by thrusting.

At Mutton Hill, two miles north of Shoreham village, massive beds of quartzite of so-called "Potsdam" age dip easterly on the west side of the hill and appear to pass conformably beneath Beekmantown beds which also dip easterly. Southeast of Mutton Hill quartzite and dolomitic limestone show the effect of great pressure and at some places have easterly dip.

The "Potsdam" quartzitic sandstone and overlying Beekmantown may be followed south from Mutton Hill through Shoreham village to Barnum Hill near the Orwell line and then into Orwell, where the marginal trace of the overthrust rocks may be seen north of Huff's Crossing.

West of Shoreham village, at Sisson Hill and west and northwest of it, and along the road from Larrabee's Point to Cream Hill are abundant exposures of the black Ordovician shales, often folded, but sometimes lying nearly flat, and always sheared. These shales show practically the same structural features as those which have been described in previous pages. It has be-

come evident that the shales hold throughout a long distance in western Vermont to much the same structural features. Near the margins of overthrust they are always excessively jammed and sheared, but may nevertheless often retain a flattish attitude, having undergone their chief deformation by shearing.

The shales outcrop at Fivemile Point and southward along the lake shore, but in northwestern Shoreham the area intervening between the shore and the road running north from Larrabee's Point is covered by the ubiquitous clay.

East of Cream Hill is Cedar Swamp, which separates the shales of Cream Hill from the "Potsdam" and Beekmantown of Mutton Hill. Shales presumably underlie most of the area of the swamp, which marks a zone of displacement.

Near Larrabee's Point, north of the boat landing, are Trenton beds in association with shales and, south of the landing, Trenton beds are underlain by others of Black River age and these by gray limestone of uncertain correlation.

In Shoreham the evidence for reverse faulting and thrusting is clear and distinct. It is even more so in Orwell at the south, as the writer has elsewhere shown.

Whiting Township.

(Brandon topographic sheet.)

Location. This township lies directly south of Cornwall. It is bounded on the west by parts of Shoreham and Orwell, on the east by parts of Salisbury and Leicester and on the south by Sudbury.

General description. For Whiting a brief description will suffice. The hard rocks are concealed by surface material over much of its area, particularly in the eastern portion to the west of Otter Creek. As already mentioned, the phyllites extend north from Sudbury through the central part of Whiting. In the northwestern part, limestone of apparently Trenton age borders the band of phyllite on the west. In the southeastern part along and near the road running from Whiting village to Leicester Junction and also south of this road are more or less detached exposures of limestone which seems to be the northern continuation of sheared, marbly and bluish limestone carrying layers and patches of yellowish-weathering rock which make up the conspicuous hills in the northeastern part of Sudbury. Eastward, these rocks join with others that are similar in the western part of Leicester.

Salisbury Township.

(Brandon topographic sheet.)

Location. The western boundary is formed by a portion of Otter Creek, which separates the township from parts of Corn-

wall and Whiting. It is bounded on the north by Middlebury, on the east by parts of the mountain towns of Ripton and Goshen, and on the south by Leicester.

General description. The western portion between Otter Creek and the railroad track is low, flat land and affords few outcrops. West of Salisbury station, in the lowland that borders Otter Creek, are a few island-like knolls of marbly or bluish limestone with layers of chamois or pinkish-buff color. The rocks frequently show thinly laminated structure. The whole assemblage is much like that found southward in Leicester and in the northeastern part of Sudbury and adjoining parts of Whiting.

A road runs south from Salisbury station, just to the east of the railroad track. East of this road and a few rods south of the station, dove-blue or marbly limestone, often with thinly-laminated structure that represents or simulates bedding, is associated with chamois or pinkish-buff colored beds and the two give an assemblage that is very much like that found in the hills in the northeastern part of Sudbury. The structure is often much like that found among the interbedded quartzites and dolomites lying to the east; at places beds which have been closely folded and now stands on end lie against others forming a gentle syncline. Between such compressed zones and the less violently folded rocks there apparently exists a displacement due to reverse faulting. These rocks continue southward. A mile south of the station, south of a cross road running east, in some outcrops of westerly-dipping beds which appeared to be conformable, bluish, marbly limestone is interbedded with chamois colored rock and these are apparently underlain by interbedded marble, chamois-gray limestone and quartzite, the latter usually in thin beds but showing one about a foot thick.

Two-thirds of a mile to the southeast of these outcrops is a hill in which the rock on the west slope and part of the summit is marbly, dove-blue rocks showing extreme effects of pressure which is expressed by conspicuous flow and fracture shearing. At the summit of the east slope of this hill are patches of quartzite which seemed either to rest on the sheared, marbly rocks or to be involved with them by thrust.

On the meridian of these rocks, about a mile south of West Salisbury village and east of the road running south from it, is another hill on the northwestern side of which are many outcrops of striped blue rock, strongly resembling the Chazy of the lake region. The beds have prevailingly westerly dip, but are strongly sheared with easterly dipping cleavage. No fossils were found. A cross road skirts this hill on the south and runs easterly to join the Farmingdale-Salisbury road. Along the cross road, to the east of the hill, is gray, siliceous dolomite like that associated with the quartzite along the eastern edge of the lowland. A few

rods east of this dolomite is marble, then more gray dolomite dipping easterly, then east of the Farmingdale road the interbedded series of quartzite and dolomite which forms an anticline between the Farmingdale road and the one that runs northward from Salisbury village on the west of Sunset Hill.

From descriptions just given, it will be apparent, by reference to the writer's first paper, that northwest of Salisbury village, marble, gray dolomite and interbedded dolomites and quartzites are involved in field relations quite like those which occur around Brandon.

West and north of Lake Dunmore, quartzite, siliceous dolomite and interbedded quartzites and dolomites have such field relations to one another as to leave no doubt, even in their present disturbed and eroded condition, of their common membership in one formation. To what extent these different rocks may grade laterally into one another the conditions in the eastern part of Salisbury do not permit statement. As has been elsewhere shown, at some places in the Vermont valley the vertical sequence is more or less plainly from basal quartzite through gray dolomite into interbedded quartzites and dolomites.

East of Lake Dunmore is a very prominent scarp of quartzite forming the western edge of the plateau. Dolomite resting on quartzite occurs above this scarp around Silver Lake. It also occurs at places around the shore of Lake Dunmore in such relations as to indicate that normally the dolomite rests on quartzite. The rocks around Dunmore and north of it are in fact more or less completely dismembered portions of the plateau.

A section from Lake Champlain eastward through Shoreham, Whiting and Salisbury to the Green Mountain plateau is comparable with one farther south extending from the lake eastward through Orwell, Sudbury and Brandon. The essential similarity is disguised but not obscured by differences in degree of displacement of the rocks. The northern section is a downthrow region in relation to the other, partly from flexure in the direction of the strike and partly from faulting, due in part probably to deformation subsequent to earlier thrust displacements. It should again be noted, perhaps, that it will apparently always be difficult to discriminate between displacements primarily resulting from pressure and those which were caused by normal faulting either along independent planes, or along those of earlier thrusting.

In the northern section the younger rocks (Ordovician) are more fully preserved and apparently show, in spite of deformation, an overlapping, probably disconformable, depositional series ranging from the "Potsdam" (Ozarkian) through "Beekmantown," Chazy and Trenton. Thrusting has partly restored the ancient Cambrian surface on which these rocks were laid down.

In the southern section the Cambrian is more fully shown (see writer's first paper).

Leicester Township.

(Brandon topographic sheet.)

Location. Leicester lies south of Salisbury. It is separated by a portion of Otter Creek from Whiting on the west and is bounded on the south by Brandon and on the east by Goshen.

General description. The rocks of this township join those of Salisbury with those of Brandon. They present practically nothing that is essentially different in respect to rock type or structure from the areas to the north and south.

The ledges in southern Salisbury are separated from outcrops in southern Leicester by the wooded flats or swampy land along Leicester River and its tributaries.

In the Huntley lime quarry, west of the Otter at Leicester Junction and west of the main quarry at some smaller holes, may be seen buff and pinkish colored beds of marble or crystalline limestone, usually standing at a high angle of dip. At the big quarry these beds are jammed in with gray dolomite and all show the effects of extreme compression; but none of the rocks indicates much in any respect as to its age.

At the so-called Swinnington quarry, southeast of the Junction and east of the Otter, marbly limestone which has been quarried is overlain by gray, magnesian rock which shows a remarkable fold in the form of a recumbent, closely compressed anticline which has been aptly called a "roll." This is pictured by the State Geologist (Seventh Report, p. 352). The roll is interpreted by the writer as the portion of a mass now largely eroded which was thrust over the marble on which it now rests. The peculiarly folded structure was probably acquired by frictional drag during thrust. Similar rolls have been mentioned in previous pages for other places in western Vermont at which apparently similar rocks were involved.

Two-thirds of a mile east of the Junction, north of the road running east from the covered bridge, are ledges of dove-blue or marbly limestone with patches of chamois-gray. Eastward these pass under drift; but about a mile to the east are ledges of strongly sheared, striped, blue, crystalline limestone not very distant from others of gray, siliceous dolomite like that which is associated with the quartzite at the east. East of these are other ledges of dove-blue limestone and its associated chamois-gray rocks and farther east the interbedded dolomites and quartzites which are much folded and form the southward continuation of the similar rocks of Salisbury and the northern extension of those in Brandon. The interbedded rocks extend in Leicester to the east of Mt. Pleasant, which is bordered on the east by a distinct scarp, at the base of which lies Mud Pond.

Lake Dunmore lies in a structural basin perhaps primarily of synclinal structure, but bounded on the west and east by faults. Those on the east are the southern extension of those marking the western edge of the plateau in Salisbury.

In some particulars the interbedded rocks of Leicester form a transition between those found farther south in the Vermont valley and those occurring over the eastern portions of the lowland in the northern townships. This transitional character is shown by thicker beds and by reddish colors which are more common at the north.

GENERAL SUMMARY.

Edward Hitchcock in his "Preliminary Report," a sort of preface to the first volume of the Geology of Vermont, wrote in substance that the rocks of Vermont were the most difficult ones to understand of any with which he had ever attempted to grapple. It does not appear in his remark whether he drew any distinctions among the different rocks; but apparently he recognized that although the geology of some parts of the state is easier to comprehend than that of other parts, the whole region is one of great complexity. The efforts of many workers have contributed only to a partial solution of the age relations and structural features of the various rocks.

In the lake region proper, as defined in this paper, fossils were found many years ago and the ages of the different rocks are now for the most part at least approximately known; but their structural relations have always been and are even now obscure. While distinct progress has been made by Wing and others in tracing the formations of the lake region into the eastern parts of the Champlain lowland, the Vermont valley and the Taconic range, it has not seemed altogether strange that Hitchcock was confounded by the obscurity which prevails over the areas which he mapped as "Eolian Limestones," in which metamorphism and deformation have introduced so much confusion.

It is not the purpose of this summary to point out in detail how the writer's views differ from those of others; but it seems as though confusion has often resulted from failure to interpret correctly the major structural features of the region.

For the sake of convenience of discussion, western Vermont may again be broadly defined as that part of the state which includes the islands of the lake and the low areas along its borders, herein called the lake region proper, the relatively low land lying between the lake region and the Green Mountain plateau, the western marginal portion of the plateau, the Vermont valley and the Taconic range. These various divisions together form a fairly broad region east of the New York boundary, reaching across the state from north to south.

The writer started out on the program of surveying this whole region. The work has been accomplished, after a fashion, for the Vermont valley and the Champlain lowland and for parts of the Taconic range and the western margin of the plateau. The survey as made has hardly been exhaustive, but has been carried out as carefully as possible in the time that has been available for the purpose. Experience has served to show how puzzling are the problems presented by the region and how elusive is any final and definite solution of some of them. However, in spite of the difficulties that stand in the way and the uncertainties that exist, there seem to be manifest such similarities among various rocks and in the field relations shown by them that some generalizations may be offered which would hardly be warranted without a survey of the region as a whole.

When the various outcrops that have been described in the preceding pages have been plotted on the several topographic sheets involved and these are placed in their proper positions with respect to each other, certain features and field relations stand out which now deserve examination and discussion.

In the first place it becomes very evident that the major physiographic features and many of the minor ones as well are primarily due to ancient deformations of the rocks which set the stage for later structural changes and the action of erosive agents. The various divisions which have been defined are all structurally homologous areas, some more obviously than others, which are at the present time largely separable only on geographic and physiographic bases. This homology consists in the essentially identical types of rocks found in each and the major structural relations which these formations have to each other. While the writer's studies in the Taconic range lack the measure of fullness of those carried out in the lowland divisions, it seems most probable that this division is only a special physiographic type whose principal features are incident to the ways in which the forces which deformed the whole region acted in the portion of the region occupied by it at different phases of its history and to certain primary variations among the various related rocks that were laid down in what is now western Vermont. It seems probable that distinctions among the various rocks of the region have often been made on secondary features and that an essential unity in rock type and structure has been overlooked.

A tendency to regard different portions of the region as things more or less apart has appeared in one form or other during and since the days of the early surveys, and it may be said that by reason of the heterogeneity that exists over western Vermont as a whole, on account of primary differences among the rocks and metamorphism and deformation, it is not surprising to find that what now appear to be subordinate or secondary

features have been emphasized and that fundamental similarities have been overlooked.

In the first place, it is well again to note that the lake with its islands differs in no essential way from the mainland areas which adjoin it; the clay or sand or bowlder drift that usually conceals the hard rock on the mainland differs only in physical properties from the water of the lake. In fact, as has already been pointed out, in many places near the lake and within its confines, clay instead of water may be said to inundate the land where the surface of the hard rock is below the present water-level. The areas of the hard rock now beneath the waters of the lake, or beneath the deposits of one kind or other which take their place, are probably primarily old stream denuded surfaces which have been generally modified by glacial action and in certain portions after inundation by water also by the waves. The topography of the lake region stands in contrast to the rest of the Champlain lowland on account of the more vulnerable character of its rocks, whose presence at the surface is a circumstance consequent upon relations produced by ancient deformations which the region underwent.

If, as seems likely, there have not been any marked displacements of the crust during or since the action of the erosive agents which shaped the present surface, then the several physiographic divisions of the region may be regarded as chiefly consequent upon relations produced among the formations by crustal disturbances.

The islands of the lake and also, without much doubt, the hard rock surface beneath the water, as well as extensive areas of the adjacent Vermont mainland over which the hard rock is partly exposed and partly hidden, are dominated by rocks which, although altered and deformed in varying degrees, are on the whole less metamorphosed and less crystalline than are the various formations of calcareous rocks found over the areas that lie to the east of the lake region. Away from the lake along surface sections from west to east at some latitudes the succession is often marked by a sort of transition from comparatively little altered rocks, through others in which fossils have been largely obliterated to highly metamorphosed rocks with dim, uncertain traces or else no suggestion of organic remains. Even along such sections it should be understood that the sequence is not one marked simply by difference of metamorphism of the rock, but is an interrupted one caused partly by deformations and partly by erosion. In some sections, on account of displacements and thrusts which have moved rocks from the east over those at the west, the change from rocks whose geological age may be fairly readily apparent, at least so far as the fossils are understood, to rocks which have been profoundly altered is abrupt.

The rocks of the lake region, including the islands and much of the adjacent mainland, as determined by their fossils, range in age from lowest Ordovician (possibly Upper Cambrian), "Ozarkian," through various horizons of "Beekmantown," Chazy and Trenton, possibly to horizons that are homotaxial with the Utica as elsewhere known. The so-called Ozarkian is an indurated sandstone, in some places apparently lying conformably beneath basal Beekmantown magnesian limestone. In New York, in the Mohawk valley and elsewhere, these two formations are described as separated by an unconformity which it is claimed has been traced into the Champlain and St. Lawrence valleys; but the unconformity in the lake region is not apparent from any physical evidence. The fossils are scanty and poorly preserved.

The East Shoreham section appears to give the complete series of the Beekmantown of the lake region, but elsewhere usually only parts of this formation are shown. The special characters of the members of this formation will not be described at this place. When all are present the thickness has been estimated as about 1,800 feet. The Chazy succeeds the Beekmantown, and at some places, as at Isle La Motte, the lowest beds of the series show indications of shallow water or shore origin, suggesting oscillations of the sea bottom and probably a disconformity. In a large number of places the Chazy rocks have a considerable thickness, but usually this formation, like the Beekmantown, is apparently only partly represented, at least in surface exposures. At numerous localities Chazy rocks, often clearly belonging to the intermediate members of the series, or so-called Middle Chazy, are overlain by beds of dense, black limestone of Black River age.. The Black River is suceeded by the basal Trenton ("Glens Falls") limestone, which is in turn followed by a series of argillaceous limestones and shales, some of which form a more or less distinctly transitional group with respect to both lithology and fossils between the basal Trenton limestone and the mud rocks that make up the youngest Ordovician of the lake region. These mud rocks are apparently of Trenton or of Trenton-"Utica" age.

Without much doubt, the original primary sequence among the various rocks now exposed to view in the immediate region of the lake was as above given and may be summarized as follows:

1. "Ozarkian" sandstone.
2. Beekmantown siliceous and magnesian limestones.
3. Chazy limestone, including some sandstone at the base.
4. Black River limestone.
5. Trenton (basal or "Glens Falls") limestone.
6. Transitional limestones and shales ("Canajoharie," Trenton, Ruedemann).

7. Later shales ("Stony Point," Trenton, Ruedemann), some of which may be contemporaneous with Utica as elsewhere known (New York).

Whether the different formations just enumerated are separated from one another or are broken within themselves by erosion intervals will not be discussed at length in this paper. Apparently our present knowledge is insufficient to decide the matter in many cases. From what is known of the relations among apparently equivalent formations elsewhere, as in New York for example, disconformities are probably present; but in Vermont the conditions make it difficult or impossible to say whether the partial representation of a formation at many places is due to non-deposition or to displacements among the rocks. At the present time there is no section which shows all these formations in their sequence. In some places a surface covering undoubtedly conceals portions of formations; but at other places parts are clearly absent, either as the result of non-deposition or from other causes.

The various formations of the lake region have clearly been disturbed and probably by more than one deformation. As a whole they have been faulted down with reference to the crystalline rocks of the Adirondack region; but in addition they show unmistakable evidence of profound compression which finds expression in disturbed relations due to fracture and reverse faulting within the various formations with varying degrees of actual overthrust, which sometimes carried the older rocks on the younger limestones and shales. The less resistant, more thinly-bedded rocks have been somewhat broken and faulted as masses, but have been more conspicuously sheared by fracture cleavage; the more massive formations were also internally deformed but were more characteristically disturbed by mass dislocation. At some places it is very evident that the rocks have been moved and are now not in their original relations to other rocks with which they are contiguous and at other places the presumption is often very strong that displacements have occurred. It is not always easy to decide whether a deformation which is clearly due to compression is a case of relatively simple reverse faulting, or whether considerable lateral movement with actual overthrust has taken place. In the preceding pages the probabilities have already been discussed for various localities.

In the lake region the base or floor on which the series of formations above enumerated were laid down is not exposed. One would suppose that at some depth or other the oldest member of the lake series which seems to be the so-called Ozarkian sandstone must rest on older rock; but rocks older than this sandstone which apparently could have formed the floor of the Ozarkian sea are not certainly known in the Vermont portion of the lake region, except the members of the Lower Cambrian formation

which have been brought to their present relative positions by thrust. Furthermore, the Ozarkian sandstone at no place where it is now exposed is, so far as the writer knows, in undisturbed condition, but on the contrary occupies its present position by thrust. On the west side of the lake the Potsdam sandstone is often in faulted relations with the members of the lake series. The Lower Cambrian rocks that lie to the east of the lake give only a vague suggestion of what is at depth in the lake region proper. Presumably these Lower Cambrian rocks extend beneath the lake at some unknown depth; but what immediately overlies them is not known.

Why the various thrusts which may be shown to exist in the immediate lake region have always cut through the Ozarkian or some younger formation it is not easy to understand. If the lake series rests on older rocks than the Ozarkian but younger than the Lower Cambrian, one wonders why such rocks do not now appear at the surface somewhere or other in the lake region. The fact that they do not and that the members of the Lower Cambrian do not appear by upthrust west of their present margin forms the basis of the conception, first clearly formulated by Logan, that there was a great lateral thrust fault by which the older masses at the east were driven over the rocks of the lake region. But of the fact that the members of the lake series have themselves in varying degrees participated in thrust movements there is now no longer any doubt.

It is possible that there exists a deep-seated plane of major thrust that cut through the roots of successive reverse faults and that this plane is beneath any rocks now exposed in the lake region and is concealed because of subsequent normal faulting which dropped all the rocks that lie betweent the Adirondack mass and the Green Mountain plateau. If such a plane exists and if it cut through pre-Cambrian rocks it might not be easy to recognize and could hardly be detected on the Vermont side of the lake.

On the New York side of the lake is a sandstone of Upper Cambrian age which is not like the Ozarkian sandstone of the lake series in Vermont. This sandstone has not been recognized in Vermont, but has a wide distribution on the east and north of the Adirondacks, where it apparently rests unconformably upon pre-Cambrian rocks. One is confronted with a problem of great complexity in trying to account for the deformations and primary conditions which could have produced the present relations.

It seems probable that so far as thrusting is concerned the situation involves some such history as follows: Possibly during a time when overlying masses of rock which are now eroded were present in the region, there occurred more or less extensive thrusts by which older formations were driven through younger ones. These great shears, as such, did not necessarily pass to the

surface at the time they occurred, although if they did, they seemingly must have had some expression there, probably as folds. In any event the effect obviously was to bring older against younger masses. This was not accomplished in any set fashion, but by irregular displacements of varying degrees. There was, however, produced a considerable regularity in the relations which certain formations came to have to one another. One may imagine that at certain places, notably in the lake region, on account of diminishing pressure, older rocks were not driven into overlying formations far enough to cause them to appear at the surface during later erosion. It seems also probable that during such deformation older rocks were often carried over relatively undeformed younger formations and that the latter were preserved until relatively recent times by a covering of more resistant rock. The present preservation of relatively soft rock was not due, however, simply to the service of a protecting covering, but was favored by crustal deformations due to normal faulting which occurred after the period of thrusting and which brought different areas of the region to a lower elevation with reference to the base level of erosion.

It seems clear that all the different rocks were subjected to a certain amount of compression, but that on account of the massive character of many of the formations involved, folding was subordinate and fracture with thrust became the dominant type of displacement.

There are good reasons for thinking that a thrust which was initiated, perhaps as a reverse fault, in one formation often sheared away from it into an overlying one and that from such behavior either the older formation or the one overlying it was driven over a still younger formation. Various modifications might have been produced. By a series of reverse faults preceding the development of a horizontal thrust the latter could be conceived as cutting the planes of the faults at depth and as driving several blocks on a common shear: If the several reverse faults were of different degrees of throw the thrust might have cut through younger rock at the west than at the east or have driven in different ways at different places, producing final effects not very different from those resulting from the mode of behavior postulated in the first part of this paragraph.

The applications of the ideas as to possible or probable thrust behavior which have just been given depend, however, not only upon the recognition of thrusting as the dominant mode of deformation of the region under compression and upon the present apparent relations which the various formations have to each other, but also upon the relations that existed among these formations prior to the action of pressure. The explanation of the conditions which now exist requires, therefore, some examination of

the question of the probable primary relations of all the rocks to each other.

For the lake region proper the probable primary sequence of the various formations now found within it has been given. On the New York side of Lake Champlain, for the areas that lie along or at various distances away from the lake, apparently studies yet remain to be carried out in detail with regard to arrangements among the rocks with special reference to displacements. In Vermont, as is evident from the descriptions that have been given, the lake rocks have been disturbed by thrusts and there may be recognized a more or less well defined zone of demarkation at the present surface between the relatively unaltered rocks of the lake region and others lying to the east which are either visibly more altered or are notably different in age and lithological character. This zone constitutes what has long been known as "Logan's line."

Regarding this zone for convenience as a line, by which symbol it would be portrayed on a map, it may be described for purposes of summary as follows: Entering Vermont from Canada in western Highgate it follows the present lake shore for two or three miles, then extends through the south-central part of Highgate into Swanton, then passes approximately through the central parts of Swanton and St. Albans to St. Albans Bay. From St. Albans Bay southward it extends roughly parallel with and near the shore in the southwestern part of St. Albans, and on through Georgia and Milton to Colchester, where it coincides with the present shore north of and around Malletts Bay. It cuts across Colchester peninsula to the shore north of Burlington and southward across Burlington and Shelburne Bays. From Shelburne Bay southward across the southwestern part of Shelburne, on through Charlotte, Ferrisburg, Waltham, the southeastern part of Addison, and the northeastern part of Bridport, the surface relations usually permit fairly definite separation of the older or metamorphosed rocks from the lake series, but drift often more extensively separates outcrops and hides relations in these townships and from Ferrisburg to Bridport the apparent line of separation is a decidedly sinuous and irregular one with encroachment eastward at some places of the members of the lake series on meridians which to the north and south are occupied by overthrust rocks.

From the Canadian boundary to Bridport the line that is being described marks for the most part an abrupt separation of the youngest Ordovician rocks, which are generally shales with some included siliceous bands, from more or less altered and metamorphosed calcareous rocks, or from massive, interbedded quartzites and dolomites that belong to the Cambrian system.

From northeastern Bridport southward through Shoreham into the northern part of Orwell the Cambrian rocks are concealed

and the zone of overthrusting is occupied by not very greatly altered rocks belonging to the Ozarkian or Beekmantown formations of the lake series which take the place of the members of the Red Sandrock formation or of much altered calcareous rock which are prominent along the margin of overthrust for so many miles in the northern townships. In the latitude of Shoreham the rocks that apparently represent the Red Sandrock series farther north are black phyllites with interbedded quartzite members. These rocks lie farther east in Weybridge, Cornwall and Whiting and emerge from beneath more or less altered calcareous rocks that may in some cases be rather satisfactorily correlated with members of the lake series. The phyllites of Whiting join southward with those of Sudbury at the northern end of the Taconic range. The phyllites and quartzites of Sudbury and Hubbardton pass beneath the calcareous rocks of eastern Orwell and northeastern Benson, which are of Chazy-Trenton age, and rise in central Orwell and in Benson to form high hills which are on meridians occupied by the Red Sandrock of Snake Mt. in Addison township.

The phyllites and quartzites of the northern part of the Taconic range are here and there overlain by Chazy and Trenton limestones with which they are now involved through thrusting and faulting. In the writer's first paper an attempt was made to show that phyllites and quartzites, like those of the Taconic hills, probably pass beneath the various calcareous rocks of the Vermont valley and join with similar rocks of the Green Mountain plateau, although attention was distinctly directed to the probability that both reverse and normal fault plane now separate the rocks of the Taconic range from those of the plateau.

A broad acquaintance with the rocks of western Vermont would, in the writer's opinion, serve to show that the fractures and displacements constituting the zone which has just been traced are only accentuated instances of many such displacements which break the rocks along their strike in the lake region, in the eastern parts of the Champlain lowland and along the western margin of the plateau. Along Logan's line, so-called, it is easier to discern the presence of thrust dislocations because of the wide difference in age and lithological characters of the rocks now in contact; in the lake region and particularly in the areas to the east the differences between rocks that lie in displaced relations are not always so readily seen.

The rocks east of Logan's line essentially form a Cambrian surface. Different maps that have been published and different descriptions of the region have recognized the presence of rocks of later age than the Lower Cambrian here and there over this surface. In some cases the rocks that with more or less definiteness may be distinguished from Lower Cambrian have a considerable extent and continuity, but on the whole, they may be

said to be fragmentary in character, as now preserved, and more or less intermingled with Lower Cambrian and possibly other Cambrian rocks.

The rocks which in this paper are correlated with the Lower Cambrian are far from being homogeneous throughout their extent. In previous pages, frequent mention has been made of the manner in which these rocks vary in lithological character in a lateral direction, even within relatively short distances, and vertically from bed to bed. Some types of rock found in the terrane have a wide geographical extent in the region, but it is not certain that at different places they belong to the same horizons. Over the region as a whole, the terrane as now displayed is distinguished by notably different kinds of rocks, some of which are extensive enough to be regarded as formations; but such differences, even though pronounced, seem to be explainable in part as due to differences in respect to sources of supply of material and to different conditions of deposition and in part to disturbances and alteration which the rocks have experienced. Over a large part of the region an ancient Cambrian surface has been partially restored by processes of thrust; it is not a perfect restoration, partly because of irregularity of thrust and partly because of erosion. Within the areas which have been surveyed the presumably younger rocks that are here and there intermingled with the Cambrian in the lowland have not been found on the higher land that borders the lowland on the east.

The rocks which in this paper are correlated with Lower Cambrian include:

1. Apparently altered derivatives of older rocks of probably pre-Cambrian age; sheared quartzitic rocks, frequently gneissoid or coarsely schistose, sometimes conglomeratic and sparingly arkosic, found at numerous places along the western marginal portion of the Green Mountain plateau and in the hilly land adjacent to it.

2. Extensive areas of white and gray, granular quartzite, frequently sheared but often without pronounced internal deformation, occurring in heavy layers or as thick masses of relatively thin beds. These rocks grade laterally and vertically into flaggy quartzites, schists, phyllites and slates. These various rocks are now found within the marginal portions of the plateau, and along the eastern portion of the Champlain lowland and mixed with graywacke quartzite are found in Weybridge, Cornwall and Whiting and in the northern portion of the Taconic range.

3. Massive, gray, siliceous dolomites and dolomitic quartzites grading laterally into one another and into quartzite and downward into sheared or massive quartzite and perhaps laterally and downward into schists or phyllites; grading upward and perhaps laterally into

4. More or less distinctly interbedded dolomites and quartzites which vary in different parts of the region with respect to thickness and color of the different members.

Members of 3 are common along the margin of the plateau and in the eastern portion of the lowland in association with different members of 2 and with different phases of 4 occur over much of the lowland, intermingled with quartzite or schist, or with calcareous rocks of probably younger age.

These different rocks appear to be parts of the same general formation. Very different kinds of rocks were probably essentially contemporaneous and all together probably originally composed an essentially conformable series. Published descriptions of the different geographical or more or less altered phases of this series have differentiated them into Granular Quartz, Talcoid Slates and Schists, Talcoid Conglomerate, Dolomite, Red Sandrock, etc. and have recognized only in part what the writer believes to be their essential contemporaneity. Into the nomenclature that has at one time or other been employed to describe these rocks there have crept some terms indicative of age which seem to be in many cases distinctly misleading in their implication.

Topographic conditions may be largely discounted. Present geological relations must reckon with the evidence that the rocks of western Vermont have been jammed, sheared, faulted and driven over one another. Ancient effects due to compression and normal displacements which apparently came later are sufficient to account for most of the field relations, if the principle of lateral variation, as discussed in preceding pages, be allowed.

Fossils have been found by different workers at various places in western Vermont among the rocks enumerated above and correlated with the Cambrian. Most of the fossils are regarded as of Lower Cambrian age.

Some observers have assigned a different and much later age to certain rocks which have not yielded fossils and which the writer regards as probably parts of the Lower Cambrian. Such assignment has apparently often been based on such features as superposition with respect to rocks probably younger than Lower Cambrian and intimate field association with such rocks. Such relations might readily have been produced by thrusts and other displacements, as has been elsewhere discussed.

Others have "hazarded" an opinion that at some places some members of the series that is herein regarded as probably Lower Cambrian may be of Middle Cambrian age; but apparently such opinion is based on the idea that the thickness which has been assigned to the Lower Cambrian is too great along certain sections in which the rocks appear to be conformable. Again it seems that sufficient account has not been taken of the deformations of the region and the probable existence of displacements in an apparently conformable series.

It is recognized that fossils have been found, as has been mentioned in this paper, which suggest a Middle or late Cambrian age for certain rocks now present in western Vermont.

The localities at which these fossils were found are in the northwestern part of the State. The rocks yielding them are in some places slates, in others, a peculiarly fragmental rock which has been referred to as an "intraformational conglomerate."

From the time when the Cambrian rocks of western Vermont, which were first called Middle Cambrian, were recognized as belonging to the lower part of the Cambrian system it has usually been supposed because of failure to discover over any considerable portion of the region, fossils that could positively be called Middle or Upper Cambrian, that rocks belonging to those horizons were never deposited in what is now western Vermont. It cannot be affirmed to-day that such rocks were ever laid down over any considerable part of it. But taking such fossils as have been found at their face values, it would appear that Cambrian rocks later than the Lower Cambrian were formed in some parts of the region.

It apparently does not follow from failure to find Middle or later Cambrian rocks preserved over the region as a whole, that such were never present. It is clearly necessary to recognize that such rocks may have been eroded. But if such rocks were ever present and were later eroded it is reasonably clear from present field relations that they were removed, at least for the most part, prior to the deposition of the various calcareous rocks of presumably later date that are now intermingled with rocks that apparently belong to the Lower Cambrian.

The present conditions in western Vermont seem to point to some sort of disturbance of the region after the Lower Cambrian rocks were laid down. This disturbance may have occurred so early in the Cambrian that late Cambrian rocks were formed only in a small part of the region or it may have occurred after Cambrian rocks younger than the Lower Cambrian were widely distributed. There seems to be no positive evidence to show which condition was more probable. The apparent result was a denuded Cambrian surface which, except as it has been more or less deformed and eroded subsequent to deformation, is what we see to-day. This eroded surface was submerged and on it were laid down rocks of younger age than the Cambrian.

On account of the profound deformation of the whole region after these later rocks were deposited, their original relations to the denuded surface on which they were laid down are everywhere greatly obscured. At no place which the writer has visited can there be clearly identified at the present time an unconformable sedimentary contact between the Cambrian and younger rocks, while at the same time, apparently little doubt may be entertained that most of the altered, calcareous rocks, with some of which the members of the Cambrian are now associated or even contiguous, are younger than the latter and separated from them by a great unconformity. This seems to be the situation practically every-

where, both in the lowland regions and in parts of the Taconic range. It is conceivable that in some parts of the region late Cambrian rocks were not completely eroded before the denuded Cambrian land mass was submerged; but if such is the case the localities are apparently few in number.

Where later Cambrian rocks remained in place after general denudation, it is not difficult to imagine that when these rocks were washed by a transgressing sea fossils of Middle and possibly Upper Cambrian age could have been involved and preserved in the basal member of a transgressing series, which member instead of being of Cambrian age would belong to a much later date. Cambrian types might or might not have been intermingled with other fossils.

The so-called "intraformational conglomerate" from its field relations often appears to be a facies of the basal member of a younger formation that was deposited on an eroded Cambrian surface. It was hoped that in Vermont, fossils might be found in the matrix of the conglomerate that would confirm this idea; but up to the present time the writer has found nothing that is conclusive.

The conglomerate formation in its Georgia occurrence was described by Walcott as a great lenticle or lentile in the Cambrian series; its present distribution and relations in some places do not seem to bear out this idea.

The conglomerate may be traced from its outcrops in Highgate southward through Swanton and St. Albans into Georgia, but it occurs as detached areas and very apparently as a facies of a formation which includes some calcareous sandstone, thinly-bedded, blue limestones and shaly rocks. The conglomerate is sometimes only slightly developed as a lateral variation of limestone beds and then is usually fine grained. In other places it is more extensive and composed of bowlders of all sizes, usually with a matrix of calcareo-siliceous material and arenaceous texture. The formation is from all appearances represented at some places in the northern townships by bluish limestones in which the conglomeratic phase in present exposures is either not at all or only sparingly present. South of Georgia, in Milton and Colchester, rocks which in a more or less satisfactory way may be correlated with this formation are only sparingly present in surface exposures. These have been mentioned in preceding pages. In Williston township near Brownell Mt. and west of it, thinly-bedded, bluish limestones were noted; but south of the Winooski River the calcareous rocks which are intermingled in surface outcrops with quartzite, dolomite, or interbedded quartzite and dolomite are striped, blue limestones and bluish or white, marbly rocks in which conglomerate was not noted.

The usually distinctly crystalline and often highly metamorphosed, calcareous rocks that are intermingled with the Cambrian

beds over the lowland region south of the Winooski River and east of the western, marginal zone of overthrust of Cambrian and other rocks on the lake series have been mentioned somewhat in detail in preceding pages. Attention was frequently directed to the resemblance which many of these rocks have to members of the lake series. These rocks have not often yielded fossils. In a few cases they have afforded obscure or recognizable markings of shells of gastropods or cephalopods on the basis of which they have been called Beekmantown, Chazy and Trenton.

Published descriptions and maps of the eastern portion of the lowland south of the Winooski River have certainly confused Cambrian rocks with others. On account of the confusion which exists it would not be easy to distinguish the various rocks from one another on a map. It does not seem surprising that Hitchcock was puzzled by these rocks and that in the absence of any means of separating them he embraced them all in one formation called the "Eolian Limestone." Later observers have apparently done what amounts to the same thing.

Since Hitchcock's time some progress has been made in separating the members of his Eolian Limestone on the basis of fossils; but apparently if we are to understand the geology of the areas of disturbed and altered rocks of the eastern part of the lowland, the Vermont valley and the Taconic range, other criteria will have to be used, as well as fossils.

In the work of finding the fossils, Mr. Wing wrought with great perseverance. Proceeding east from the lake region he "identified" the Trenton east of the "central belt of slate" in Leicester, Cornwall and Middlebury. He found the Chazy at West Rutland, and Trenton rocks in the northern hills of the Taconic range. The Chazy was described as affording fossils in Leicester, Cornwall and Middlebury, while by means of the "striped stratum" the Chazy was traced into the western part of Brandon, in the fields and quarries of that town, and from Brandon southward into Pittsford and northward into Salisbury. Beekmantown (Calciferous) beds were also described as occurring in Salisbury, Leicester and Brandon with their fossils.

In a section reproduced by Dana[1] from Wing's notes and intended to show the arrangement of the rocks from west to east, beginning with the Red Sandrock in eastern Shoreham and extending to the quartzite east of the main belt of "Eolian Limestone" in Leicester, beds are shown as Lower and Upper Calciferous which probably are interbedded dolomites and quartzites belonging to the Lower Cambrian.

From the investigations of Wing and from the writer's studies, it appears that Chazy and Trenton rocks are present in the main belt of the "Eolian Limestone." The Beekmantown may be present in the western part of this belt, but the data are

[1] Amer. Jour. Sci., Vol. XIII, May, 1877.

not conclusive. Some of the rock so described appears to be Chazy and some of it is Cambrian.

From the evidence that has come in of various kinds, it now appears that a broad region of denuded Cambrian rocks was gradually submerged in Ordovician time and was transgressed by an Ordovician sea. The overlap probably began at the west, but from present field relations it is not clear just how the transgression proceeded. The altered calcareous rocks now distributed among the Cambrian rocks over the eastern portion of the Champlain lowland and the Vermont valley and parts of the Taconic range are probably largely the eastern representatives of members of the lake series. By faulting and thrusting the younger rocks have been much disturbed, together with the Cambrian floor on which they originally lay. The Cambrian beds have in many places been thrust into, through and over the younger limestones. In the process the latter have been sheared and metamorphosed so that they can be with difficulty identified with their representatives farther west near the lake.

The character of the basin in which these younger rocks were deposited is not now clear. It seems probable that there was in general a sort of trough produced by a warping of the crust and that there occurred a sort of periodic pivotal oscillation of land and sea bottom, producing retreat and advance of the strand line. One of these seems to have occurred at the close of the Middle division of the Chazy and another at the close of the Upper Chazy. Similar episodes may have occurred during the Cambrian. The older parts of the trough were, however, gradually deepened and the positive areas were slowly submerged. The Beekmantown apparently never reached far to the east, but part of the Chazy encroached eastward as the trough widened. A positive movement confined the Upper Chazy to the present lake region, but a resubmergence brought in the Black River and Trenton. Whether the later mud rocks ever lay over the disturbed areas east of the lake it is hard to tell. How far east the lake rocks may once have extended may only be conjectured.

There are reasons for thinking that the Cambrian rocks and the younger rocks involved with them have in general moved as a whole for a considerable but indeterminate distance westward over the eastward extension of the lake rocks. In Ferrisburg, along Lewis Creek, the Ordovician shales extend a considerable distance to the east of the irregular margin of thrust overlap of older rocks. These shales appear to be on the under side of a great lateral thrust. At numerous places along the present shore of the lake members of the Lower Cambrian or limestones clearly older than the shales lie on the latter by thrust.

At some places also there are indications of remnants of overthrust rocks isolated among the shales and now some distance removed from the apparently recessional margin of older rocks

lying to the east of them. It seems possible that isolated patches of quartzite found among the shales in the flat land in the western part of St. Albans township may be such remnants. The thought occurred that these outcrops might be exposures of older rocks that had been thrust through the shales, but such history seems unlikely. That the quartzite belongs to a different formation from the shales is apparent, for no such rock has anywhere been found making up a part of the shale formation.

In Orwell there are detached masses of massive Beekmantown limestone which are apparently surrounded by shale and which may be thrust-erosion inliers of older rock.

SUPPLEMENTARY NOTE.

During the summer of 1923 the ledge in the bank of Rock River, at the bridge near Johnson's farm, was revisited. A number of additional fossils were found, among which were well preserved valves of *Nisusia* (*Orthisina*) *festinata* (*Billings*) and the pygidia of *Eodiseus* (*Microdiscus*) *speciosus* (Ford). These fossils were sent to Dr. Ruedemann of Albany for his inspection. Dr. Ruedemann confirmed the writer's recognition of the trilobite and identified the brachiopod.

The ledge in which these fossil fragments were found is just north of the west end of the bridge. The outcrop yielding fossils is small and partly covered with soil, but the rock seemed to be in place. In lithology it is not just like the banded limestone that lies in the bank just beneath and which forms the bed of the stream above and below the bridge.

The fossils are clearly of Lower Cambrian age; but it is not certain that all the limestone associated with the rock carrying the fossils is of similar age.

PROGRESS OF STREAM GAGING IN VERMONT

During the Two-Year Period Ending September 30, 1922.

C. H. Pierce.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY.

WATER RESOURCES BRANCH

Boston, Novemer 20, 1922.

To the Honorable, The Governor of Vermont,
State House, Montpelier, Vt.

Dear Sir:

During the biennial period of 1921-1922, the investigation of water resources of Vermont has been carried on by the United States Geological Survey in cooperation with the State of Vermont, the cooperating state official being Mr. H. M. McIntosh, State Engineer, during 1921, and Mr. George A. Reed, State Engineer, during 1922.

The work of measuring the flow of the rivers has been continued during these two years, and the results of stream gaging at ten stations are shown by the accompanying tables. Efforts have been made to continue the records throughout the winter periods, and this has been very successful, despite the fact that very low temperatures are experienced at times. The maintenance of the gaging stations during the winter and the making of measurements under ice conditions are much more difficult and expensive than the maintenance during the summer months, but inasmuch as the lowest stages of the rivers in Vermont are as likely to occur during February as any other month of the year, it seems very essential to obtain information of the flow during the winter periods.

In addition to the work of maintaining gaging stations mentioned above, we have also made a tabulation of the existing water power developments and notes as to where additional power could be obtained. Although the most obvious power sites have already been put into use, there still remain many opportunities for additional power development. With the increasing difficulties in obtaining fuel for steam power, it is apparent that more difficult and expensive water power development will be made use of in the near future. A study of the stream flow records will show that a very large percentage of the total run-off from the rivers goes to waste during the spring months and at other times when